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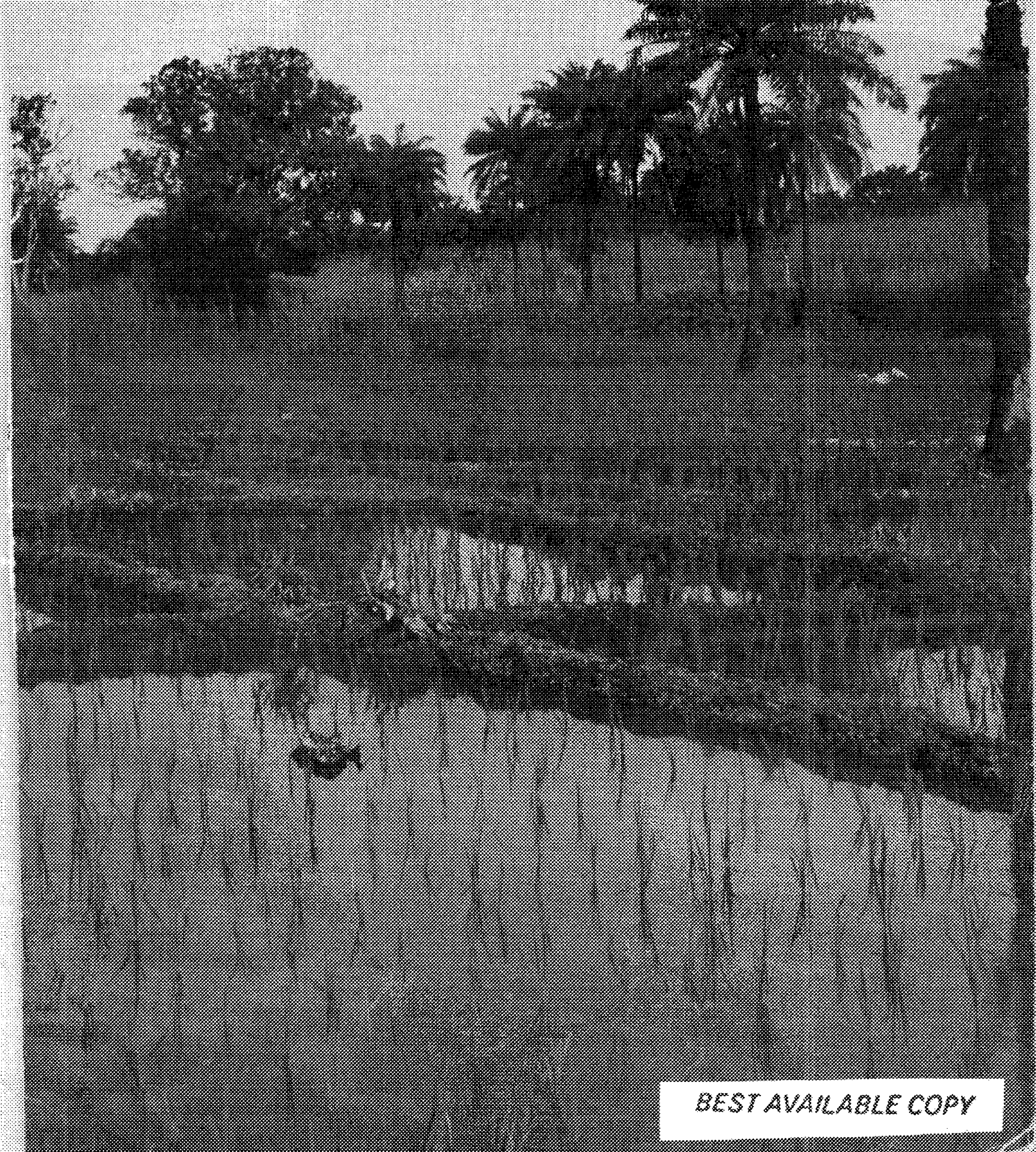
WETLANDS AND RICE IN SUBSAHARAN AFRICA

Edited by A.S.R. Juo and J.A. L[illegible]



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FOREWORD

An international conference on utilization of the wetlands for rice production in tropical Africa was held at Ibadan, Nigeria, 4-8 November 1985. The conference was jointly organized by the International Institute of Tropical Agriculture (IITA), the National Cereals Research Institute (NCRI) in Nigeria, and the Land and Water Development Division (LWDD), Ministry of Agriculture and Natural Resources in Sierra Leone.

At the opening session, Osmond Gordon, Director of LWDD, outlined the major objectives of the conference:

- To assemble specialists in rice improvement and soil and water management from Africa, Asia, and other regions to discuss ways and means of intensifying wetland use in tropical subsaharan Africa.
- To identify priorities for research programs in wetland soil and water management and cropping systems that would benefit smallholding farmers in the region.
- To make national governments and international agencies aware of the potential of wetland rice in alleviating the food crisis in Africa.

More than 100 participants attended the conference. They included scientists from 8 African countries (Benin, Guinea, Ivory Coast, Liberia, Nigeria, Sierra Leone, Tanzania, and Togo), several Asian, European, and North American countries and international research and development institutions or agencies including the International Rice Research Institute, the West Africa Rice Development Association, the Food and Agriculture Organization of the United Nations, and the World Bank.

Dr B.B. Wudiri, Director of NCRI, and Dr B.N. Okigbo, Deputy Director-General, IITA, spoke at the opening session of the conference and both called for intensified use of the wetland resources for rice production in tropical Africa. They emphasized that rainfed rice can be produced in the region, but efforts to extend production must be supported by research and planning to develop techniques and infrastructures suitable for local conditions.

Invited speakers from Nigeria, Sierra Leone, China, Japan, the Philippines, the Netherlands, and the USA discussed the state of the art and future strategies in rice research and development, wetland

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distribution and classification, and methods for improving water management and farm mechanization. A postconference field tour took participants to a government-sponsored project that is under way to develop the wetlands near Bida, central Nigeria.

We at IITA were pleased with the quality of information presented at the conference and felt that many of the papers deserved wide dissemination.

Special acknowledgment goes to the members of the conference organizing committee who successfully brought together many leading scientists from the North and the South, East and West to contribute and share the most pertinent information on the wetlands and on rice production in tropical Africa.

On behalf of the conference organizers, I wish to thank the government of Japan for providing the financial support to cover the travel expenses of African and Asian participants and the cost of publication of this book.

Laurence D. Stifel
Director-General, IITA

INTRODUCTION

Tropical subsaharan Africa has a total of 200×10^6 ha of wetlands that exist in the form of small inland valleys, river floodplains, inland basins, and coastal wetlands. At present, an estimated 3×10^6 ha of these lands are used for cultivation of rainfed lowland rice and there are few irrigated paddies.

Yet the development of the wetlands for the cultivation of rice and other food crops could be a major step toward solving the food crisis that has resulted from the erratic rainfall during the past decade coupled with the badly degraded soils that have reduced yields of food crops in the uplands.

To millions of Asians, rice is the ultimate food crop. Under tropical conditions with sufficient water and fertile soils, two or three crops can be grown in a year with sustainable yields of 3-5 t/ha. In fact, intensive rice cultivation has meant food sufficiency for many of the world's most densely populated countries.

In subsaharan Africa, too, rice could be intensively cultivated, given careful attention to technical, environmental, and socioeconomic constraints. This book discusses recent advances in research and development of the wetlands and rice as well as the feasibility of adapting some of the Asian rice-growing techniques to African conditions.

During the last century, much time and money were spent attempting to transfer Western technology, particularly for upland crops, to developing countries. Experiences gained to date should help African researchers and planners in determining their priorities and strategies in adapting Asian technologies to African wetland agriculture.

In Asia, the conventional breeding approach focuses on broad genetic variability and is concerned with an environment that is relatively stable or what is called "a narrow environmental target" — the long established paddy fields. In contrast, the wetland and rice ecosystems in tropical Africa differ greatly and are in a state of flux. Thus, the Asian approach may not be suitable for Africa; perhaps the objectives for rice breeders in Africa should be to develop varieties to meet site-specific variables in the wetlands while incorporating resistance to rice blast, yellow mottle virus, gall midge, stem borers, and iron toxicity.

As the wetlands are gradually developed and measures are introduced to control the water on the fields, the productivity of rice-growing increases and stresses decrease. For rice production, water is the great equalizer.

Japan, Taiwan, and South Korea have intensified rice production on smallholdings mainly through mechanization, and China has done so mainly through manual labour. Neither model is regarded as particularly suitable to African farmers, but elements of both may be useful. For example, to ease the serious labour bottleneck during the cropping season, some forms of mechanization need to be introduced. One approach is to develop farm tools and implements that are relatively simple and that, within a short time, can be manufactured and serviced locally.

The greatest challenge to wetland development and rice production in Africa is technology transfer. Invited papers from Nigeria and Sierra Leone attempted to address this complex issue, the former emphasizing the long-term investment in human and physical infrastructure and the latter calling for improvement of upland and valley bottoms as a whole farm unit. All the participants recognized that successful agricultural development and extension programs depend largely on the wise choice of technologies as well as the dedication and commitment of the men and women entrusted to do the job.

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WETLANDS IN SUBSAHARAN AFRICA

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Area and distribution

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Abstract *The wetlands in tropical subsaharan Africa — that is, in the warm zone with a growing period of 150 days or more (FAO 1978) — can be categorized as coastal plains, including deltas, estuaries, and tidal flats; inland basins, comprising extensive drainage depressions; river floodplains, consisting of recent alluvial deposits bordering rivers; and inland valleys, the flat-floored, relatively shallow valleys that are widespread in the undulating landscape (dambos, fadamas, bas-fonds, inland valley swamps). These are lands in which the wet conditions influence the possibilities for land use. The excessive wetness may be caused by flooding or by high groundwater tables and ponding. An inventory showed that the relatively small, inland valleys constitute between 8.5% and 20% of the total area in subhumid and humid West Africa. A conservative extrapolation for tropical West Africa is 850 000 km^2 (7% of the total area). Other categories of wetlands, as determined from the FAO soil map of Africa (1977), are coastal wetlands, 165 000 km^2 (1.5%); inland basins, 1.1 million km^2 (9%); and river floodplains, 300 000 km^2 (2.5%). The main constraint to rice cultivation in the wetlands is the coarse soil that prevails in the sedimentary formations and granitic rocks. Acid and potentially acid sulfate soils are widespread in the coastal wetlands. In the inland basins in the dry zones of the inventory area, salinity and alkalinity are extensive. The only common characteristic of the small inland valleys is their great heterogeneity, both within the valleys and between them.*

The African continent consists almost entirely of a great continental shield of Precambrian age (more than 1 billion years old), which originally formed part of Gondwanaland, the ancient continent that also comprised South America, India, Australia, and Antarctica. During the Mesozoic era, some 200 million years ago, Gondwana-

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land broke up into blocks that drifted apart (continental drift) into their present positions.

The Precambrian rocks that underlie most of the African continent are called the basement complex comprising granitic, migmatized crystalline rocks and associated metamorphic rocks like gneisses, schists, and amphibolites. The basement complex is exposed over about one-third of Africa. It is bounded to the north by the Atlas mountains consisting of Jurassic limestone, Carboniferous metamorphic rocks and Precambrian granites and metamorphic rocks. In the south, the Cape system, composed of sandstones, shales, and quartzites, borders the basement complex. Precambrian intrusions have given rise to laccoliths, sills, dikes, etc. throughout the continent. These formations are made up of dolerites and gabbros. Before the Gondwana disruption, sediment was deposited extensively in downwarped continental basins like the Volta and Congo basins. Old sedimentary formations (Paleozoic) overlie the basement complex in these places.

During and after Gondwanaland's breakup, horizontal and vertical epeirogenic movements fractured the continent causing, for instance, the Rift Valley of eastern Africa, extending from the Red Sea in the north to Malawi in the south, as well as the troughs in which the Niger and Benue rivers are situated. The fracturing also caused the formation, in low places, of inland seas and lakes, for example the Iullemeden basin and, again, the Congo basin. New sedimentation phases deposited younger rocks in the troughs and depressions: Cretaceous sandstones, shales, and coal measures are found in the Niger and Benue troughs and Cenozoic up to recent deposits occur in the Congo basin. The latter deposits form an extensive alluvial/lacustrine plain of about 150 000 km^2 in the centre of the basin. In the Chad basin Quaternary deposits, consisting of poorly consolidated sandstone, shale, and marl, directly overlie the basement complex. Pleistocene and recent alluvial and lacustrine deposits occur in the central part of this basin. Tertiary continental formations are called continental terminal in northern Africa. They form the Kalahari system in the southern part of the continent and include the eolian deposits in the Sahara and the Kalahari deserts. Sedimentation is ongoing in the river floodplains (fluviatile), the lakes (lacustrine), and the coastal plains (marine).

THE GEOMORPHOLOGY

Characteristic of the African geomorphology is the occurrence of vast peneplains, which are the result of a series of planation or erosion cycles. Already during the Jurassic period, preceding the Gondwana disruption, extensive erosion caused the formation of a nearly level plain, the so-called Gondwana surface. Simultaneously, continental basins were filled with detritus from adjacent eroding areas, thus adding to the smooth appearance of pre-Cretaceous Africa. Relics of the Gondwana surface can still be found in Africa, for example the high plateaus of the West Cameroon mountain range.

In the Cretaceous period and later, dislocation, fracturing, and faulting of the continent caused new erosion and planation cycles (the post-Gondwana, African, and post-African planation cycles). They resulted in the formation of the many extensive and remarkably level, gently undulating plains and plateaus throughout the continent. The various planation surfaces are commonly separated from each other by distinct scarps or by dissected transitional zones. African plains were formed mainly during the Pliopleistocene age and occur at elevations between 50 m and 1500 m above sea level. These plains and plateaus are dissected by streams and rivers, usually in a dendritic (nonoriented) drainage pattern. Locally, steep remnants of older plateaus (mesas) or granitic and quartzitic inselbergs and ridges arise from these plains. Such inselbergs and ridges have resisted weathering and erosion. Other geologic variations too — hills and mountain ranges — occur throughout the continent. Partly, these are of volcanic origin (e.g., the Eocene basalt plateaus of the Ethiopian highlands).

CLIMATE

This inventory of wetlands in Africa confines itself to the tropical subsaharan zone — that is, the area in Africa having a growing period of 150 days or more (Fig. 1). The growing period is the continuous period during the year, in which rainfall exceeds half the potential evapotranspiration until the time when rainfall falls below full evapotranspiration, plus a number of days required to evaporate 100 mm of soil moisture reserve (FAO 1974). The total area in Africa with a growing period of more than 150 days is 12.2 million km^2, or about 40% of the continent, including Madagascar. For wetland rice cultivation, areas with cold (mean temperature over growing period less than 6.5°C) or cool (6.5-20°C) temperatures are excluded from the inventory (Fig. 1). Their total area is 1.4 million km^2, just over half of which is located in the zone where the growing period extends for 150+ days.

Within the inventory area, climatic differences are still large. Total annual rainfall varies from 500 mm in the dry parts of the Sudan savanna to 1500-2000 mm in the equatorial forest. Extreme rainfall occurs in the coastal zones of Sierra Leone/Liberia, Nigeria/Cameroon, and eastern Madagascar: annual rainfall totals are more

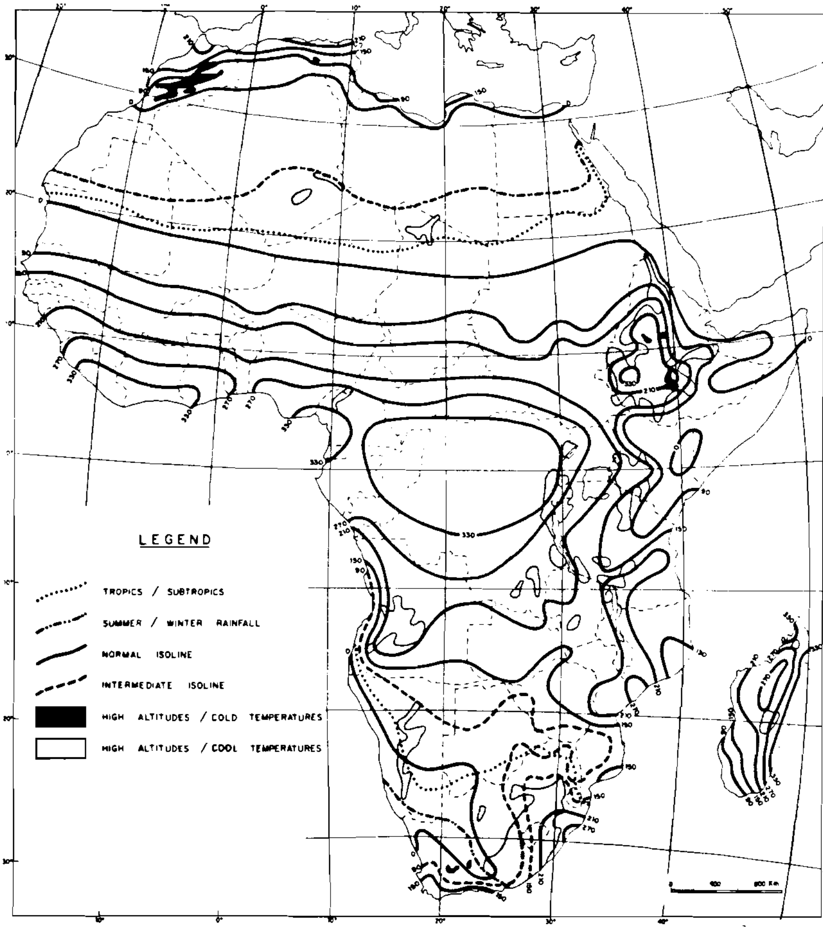

Fig. 1. Major climatic divisions and lengths of growing period zones in Africa (FAO 1978).

than 2500 mm in these areas. Rainfall distribution ranges from monomodal in the northern and southern parts, having one distinct humid period, to bimodal toward the equator where, largely under the influence of the intertropical convergence zone, two rainy seasons occur.

WETLANDS

Wetland can be defined as land subject to excessive wetness, to the extent that the wet conditions influence the possible land uses (Van Diepen 1985; adapted). Wetlands comprise soils with impeded drainage either because of flooding or because of a relatively high groundwater table, including ponding. Flooding, usually accompanied by scouring and sedimentation, refers to the superficial passage of water originating elsewhere, whereas high groundwater tables and ponding refer to the accumulation of water in and on an area that is relatively low and flat.

Wetlands can be categorized as: coastal plains, inland basins, river floodplains, and inland valleys.

The first three categories refer to distinct physiographic units that even at the present broad level of inventory can be easily identified from FAO's soil map of Africa (FAO 1977) (Fig. 2). The inland valleys are relatively small and cannot be shown on such maps.

Coastal wetlands comprise deltas, estuaries, and tidal flats. Deltas are formed where rivers flow into the oceans. The rivers

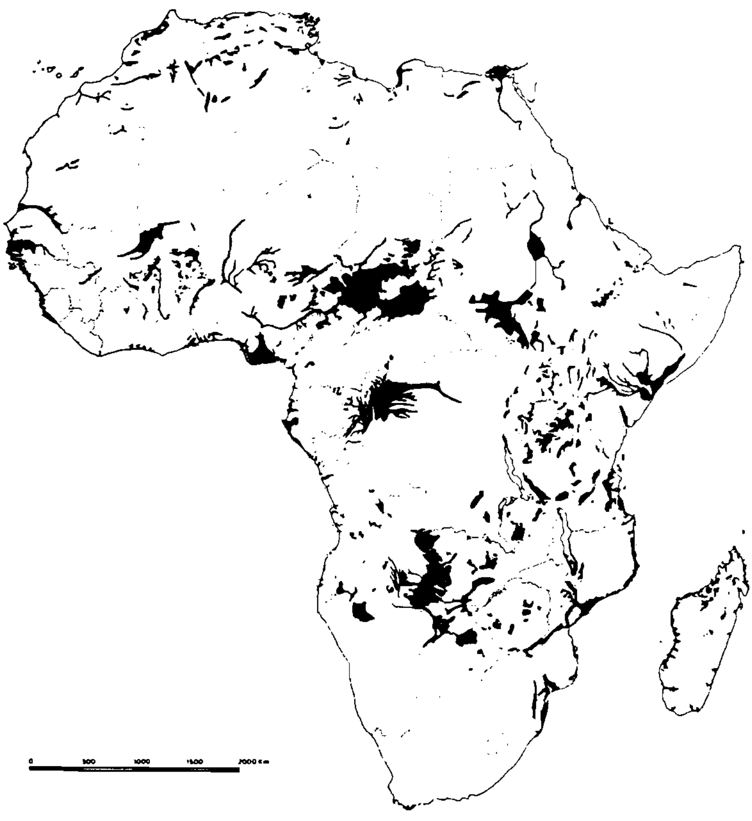

Fig. 2. Distribution of flat wetland soils in Africa (van Dam and van Diepen 1982).

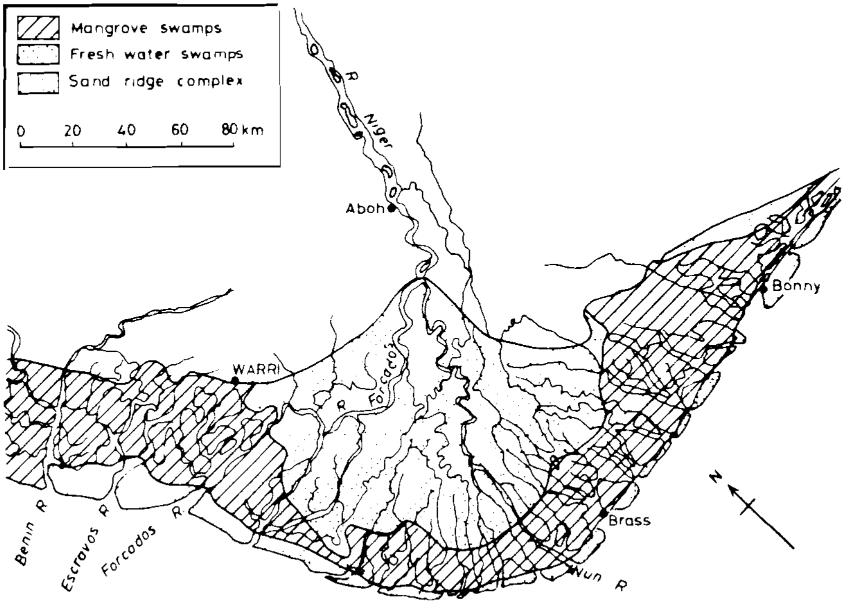

Fig. 3. Morphologic characteristics of the Niger delta (Faniran and Jeje 1983).

deposit their large volumes of suspended load as their stream velocity suddenly drops. Sedimentation is enhanced by the salt water, which breaks up the flocculent masses of fine particles. Longshore drift and current are low. A typical delta is formed by the Niger in Nigeria (Fig. 3). The characteristic delta sequence is freshwater swamps in the upper parts, which, with the exception of the river levees, are subject to annual flooding; saline mangrove swamps, subject to tidal flooding, in the lower stretches; and a complex of sandy ridges along the coastal fringe (Faniran and Jeje 1983). Other large deltas are formed by the Rufiji in Tanzania and the Zambezi in Mozambique.

Estuaries (Fig. 4) are funnel-shaped river mouths, characterized by tidal sedimentation. Sediment supply is low, relative to river discharge (Allen 1970). Saltmarshes occur along the sides and intertidal sandbanks and islands in the centre (Fig. 4). The proportion of these banks and islands increases headwards in the estuary. In Africa a good many rivers have an estuarine mouth, e.g., the Zaire, the Cross River (Nigeria), the Gambia, and the Corubal (Guinea Bissau).

Tidal flats (Fig. 5) are longshore tidal sedimentation areas that are usually sheltered from wave action by protective sand barriers at their outer fringes. Inlet channels cut through these barriers locally, to allow for tidal flooding. Typical tidal flats occur along the coast from Nigeria to Guinea Bissau. Huge sandbars have formed here between the ocean and the tidal flats (lagoons) under the influence of west-east longshore currents.

Soils in the coastal wetlands, classified according to the *Legend* of the soil map of the world (FAO 1974) include thionic Fluvisols (acid and potentially acid sulfate soils of the mangrove swamps), dystric Gleysols and Histosols (poorly drained soils of the freshwater swamps), gleyic Solonchaks (poorly drained saline soils), and Arenosols and sandy Regosols (coarse soils of sandbars and dunes).

Inland basins comprise the extensive drainage depressions that occur throughout the continent. Also included in this category are the inland deltas of the Niger river in Mali.

In the upper part of the inland Niger delta, the river is deeply

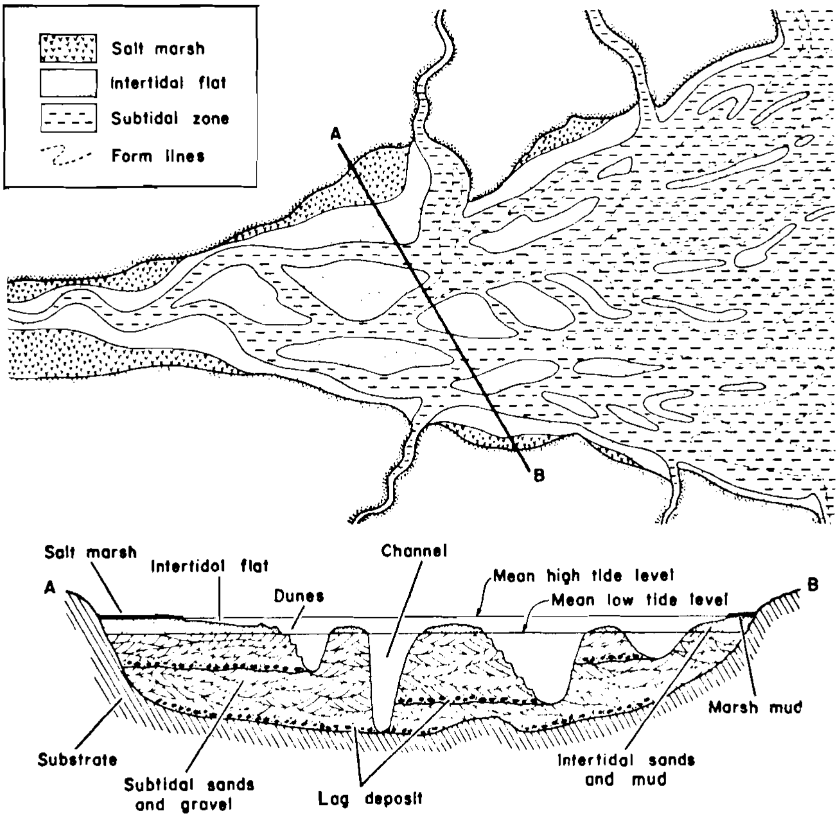

Fig. 4. Sedimentation in an idealized estuary (Allen 1970).

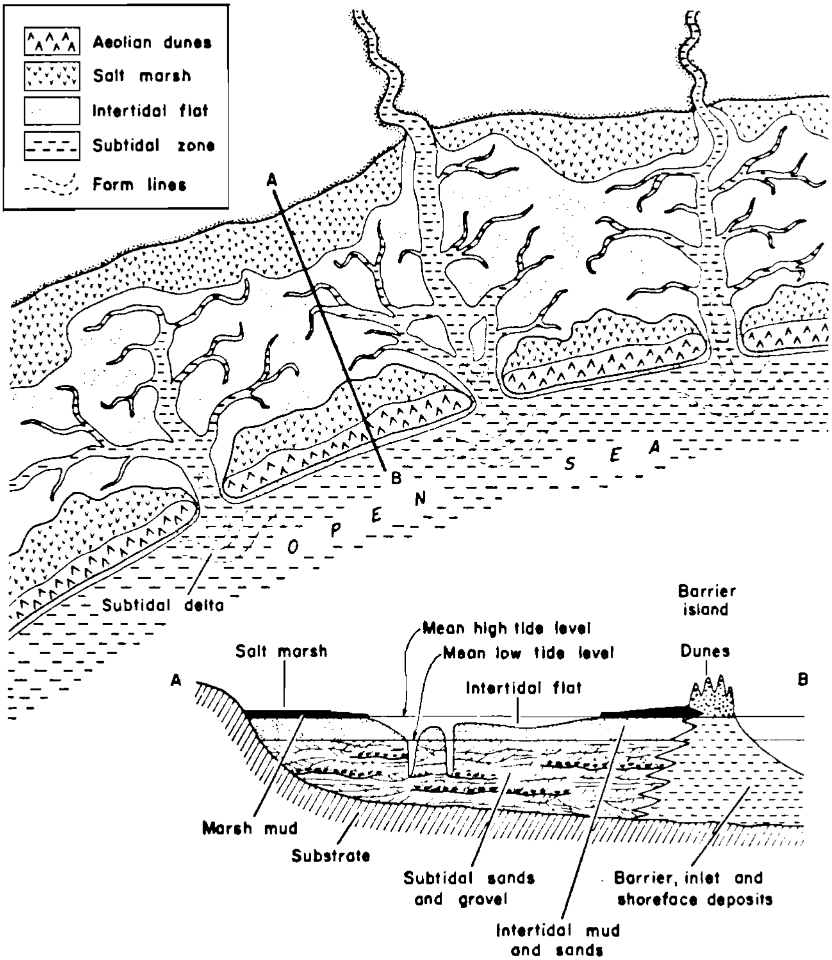

Fig. 5. Sedimentation in an idealized tidal flat protected by a sand barrier (Allen 1970).

incised in its own sediment. Farther south, below Segou, the river overflows its banks in the wet season (July–September) and below Macina an extensive braided river system has developed. Soils are mainly Gleysols and Fluvisols.

In south Sudan, the Upper Nile basin is a downwarped clay plain with many rivers that, in the rainy season (July–September), overflow their banks. Soils in the plains include fine-textured pellic Vertisols and, in the lowest parts, mollic Gleysols. The depression in which Lake Chad is located is the largest inland basin of the inventory area. The lake lies at an altitude of only 200 m. The soils, resulting from Pleistocene and recent alluvial and lacustrine deposits, are mainly pellic Vertisols, including sodic and saline phases and solodic Planosols and Solonetz.

The Congo basin, comprising poorly drained dystric and humic Gleysols and, in the lowest places, dystric Histosols, can be considered transitional between an inland basin and an extensive system of river floodplains, which include dystric Fluvisols.

In Zambia, the plains and shallow swamps near Lake Bangweulu and the Kafue flats comprise soils that are relatively rich in bases: eutric Gleysols and eutric Histosols.

Eutric Fluvisols have developed in the lacustrine deposits of Lake Rukwa and Lake Eyasi in Tanzania. They are medium- to fine-textured and include, locally, pellic Vertisols. In the slightly higher surroundings of Lake Rukwa, Planosols have developed. Solonchaks occur around both lakes.

A floodplain is a wide, flat plain of alluvium bordering a stream channel. Periodically flooded by water from the channel, it comprises levees, floodbasins, point bars, and oxbow lakes (Fig. 6). Levees are the natural embankments of a river. They are formed by sediment deposited during flooding. Deposition is greatest near the river, because, upon overflowing the banks, the water suddenly loses velocity. The large, heavy particles are deposited first and form the levees. These are mostly not more than a few metres high but can be much bigger. Finer particles

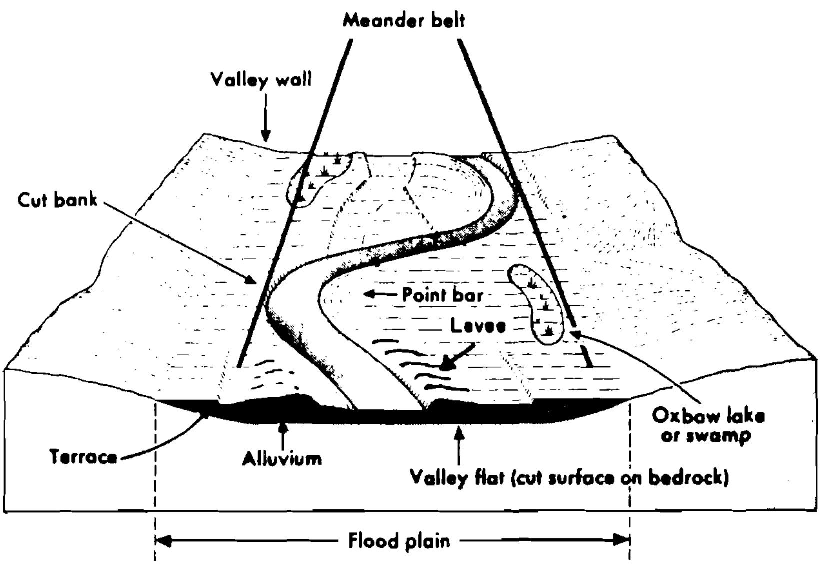

Fig. 6. An idealized floodplain (Bloom 1969).

are deposited farther away and form the relatively fine-textured soils in the lowlying and poorly drained floodbasins or backswamps. A river with a well-developed floodplain generally flows in broad regular curves, called meanders. At the outside of the curves, the river undercuts its own sediment. On the inside of the curves sandy and gravelly point bars are built. As a result of extreme curving, a meander may cut off its own channel. The remaining channel segment is called an oxbow lake. In time oxbow lakes fill with remnants from floods. River terraces are formed upon lowering of the base level, which causes the river to start eroding its own sediment. If the load in the riverbed is excessive, a braided river system forms, consisting of many interconnecting channels between sandbanks. Banks and channels of such a system are unstable and subject to much shifting. The sandbanks are generally submerged during floods.

Most rivers in Africa have well-developed floodplains at least in their middle and lower stretches. Depending on local topographic and geologic conditions, the widths vary from tens of metres to tens of kilometres. Lengthwise, the floodplains may extend up to several hundred kilometres. The floodplains of large African rivers can be readily identified even on small-scale maps. They occur along the Gambia river, the upper, middle, and lower Niger; the Benue; the Zaire; the Zambezi; Limpopo; Tana; White and Blue Nile; and the Chari rivers. The soils in these floodplains are mainly Gleysols and Fluvisols. Soils on the terraces, which are older and which occur in somewhat higher physiographic positions, may show some profile development. They include gleyic Cambisols and Luvisols mainly (e.g., Black Volta).

The term "inland valleys" refers to the numerous flat-floored and relatively shallow valleys that occur in the extensive undulating plains and plateaus that make up most of the African landscape. They are known as dambos in eastern and central Africa (Mackel 1974; Mangai 1985), as fadamas in northern Nigeria and Chad (Savvides 1981), bas-fonds or marigots in francophone African countries (Kilian and Teissier 1973), and inland valley swamps in Sierra Leone (Millington et al. 1985). Their catchments range in size from 100 to 2000 ha, depending on local topography. They vary strongly in their morphologic, hydrologic, and pedologic characteristics.

Longitudinally the valleys can be continuous and smooth or interrupted and stepped. Continuous valleys occur in lithologic formations with little structural variation, like sedimentary rocks. Stepped valleys occur in the migmatized basement complex where hard rocks (granites, quartzites) alternate with softer formations (schists, gneisses). The flatter sections that

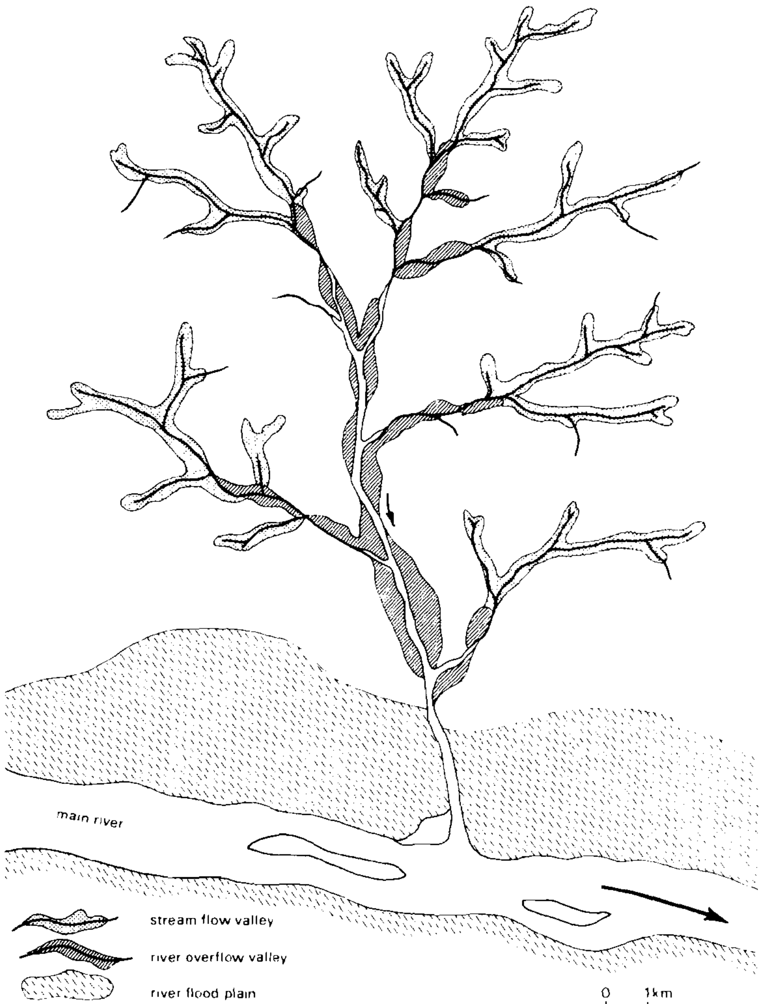

Fig. 7. Schematic location of the two categories of inland valleys and a river floodplain (Savvides 1981).

narrow valleys in the resistant formations. In cross section, three types can be distinguished:

- Narrow valleys with relatively steep and straight to convex sideslopes, occurring in relatively hard rocks (granites, quartzites);
- Intermediate valleys with moderately steep, concave sideslopes, in moderately hard rocks (schists, gneisses); and

- Wide valleys with gentle, concave sideslopes, in relatively soft formations (sedimentary rocks, amphibolites).

With respect to hydrologic characteristics, two main types can be recognized (Saviddes 1981; Fig. 7):

- Stream-flow valleys in the uppermost parts of the river catchments. Apart from rainfall, runoff and seepage from the adjacent uplands are the main water sources. These valleys have a poorly defined, more or less centrally located, shallow stream channel, which doesn't exist in the upper parts. The flat bottoms of the valleys vary in width from about 10 m in the upper portions to about 100 m in the lower stretches. Catchment sizes vary from 2-5 km^2 on granitic formations to 20-50 km^2 in sedimentary rocks (Smaling et al. 1985a,b).
- River-overflow valleys downstream of the stream-flow valleys. These valleys have a distinct stream channel that, in general, is located at one side of a small floodplain (up to 200 m wide) in the valley bottom. The main water source is overflow from the river, rather than runoff or seepage.

The soils of the valley bottoms vary widely in their characteristics, both within and between valleys, because of morphogenesis, location, hydrologic regimes, lithologic origins, and climatic conditions. Chemically, they can be rich or very poor. Their texture ranges from sand to clay; in cool climates at high elevations, peaty topsoils may develop or the soils may be peaty throughout (as in Kenya and Burundi). Drainage ranges from moderate to very poor, and floods differ widely in depth, duration, and velocity. In general, however, the textures of the soils as well as their chemical characteristics reflect the soils of the surrounding uplands and the parent material from which they are derived. Thus, broadly generalized, coarse infertile soils prevail in valley bottoms of poor and acid rocks (sandstones, granites, quartzites, rhyolites); coarse to medium-textured soils of low to moderate fertility occur in intermediate rocks (hornblende granites, quartz-feldspar gneisses, diorites, andesites) and medium to fine, relatively fertile soils are found in the valley bottoms of areas with rich parent rocks (amphibolites dolerites, basalts, hornblende gneisses, shales, siltstones).

AREA ESTIMATES

In the framework of IITA's Wetland Utilization Research Project, my colleague and I made an inventory of wetlands and their potential for rice cultivation in West Africa (Hekstra and Andriesse 1983). The objective of this project is to find techniques suitable for smallholders to use in rice-based farming systems.

Table 1. Wetlands in West Africa: types in each region and agroclimatic zone (Hekstra and Andriesse 1983).

Zone/ region	Area ('000s km²)	Wetlands ('000s km²) Coastal, inland basins	Flood plains	Inland valleys Overflow	Stream-flow
EQUATORIAL	865	29.0-48.6	13.5-40.0	26.3- 80.5	42.7- 94.9
Plains	527	29.0-48.6	10.1-29.8	21.1- 57.4	33.0- 68.3
Coastal	100	25.0-40.0	1.0- 5.0	1.0- 4.0	1.0- 3.0
Interior	427	4.0- 8.6	9.1-24.8	20.1- 53.4	32.0- 65.3
Basement complex	376	2.5- 4.5	6.5-19.7	18.6- 49.3	31.5- 62.2
Sediment	51	1.5- 4.1	2.6- 5.1	1.5- 4.1	0.5- 3.1
Plateaus[a]	220	—	2.2- 5.5	3.8- 14.8	3.8- 14.8
Highlands[a]	118	—	1.2- 4.7	1.4- 8.3	5.9- 11.8
GUINEA	1295	7.7-26.1	40.7-89.7	53.8-113.6	58.5-124.2
Plains[b]	648	7.7-24.2	30.9-55.4	36.0- 68.1	16.0- 40.3
Basement complex	389	0.0- 3.5	17.9-29.5	28.3- 47.4	13.4- 41.6
Sediment	259	7.7-20.7	13.0-25.9	7.7- 20.7	2.6- 7.7
Plateaus	404	0.0- 0.3	4.3-20.4	4.9- 21.4	32.4- 52.6
Basement complex	374	—	3.7-18.3	3.7- 18.7	31.2- 49.9
Sediment	30	0.0- 0.3	0.6- 2.1	1.2- 2.7	1.2- 2.7
Highlands	243	0.0- 2.4	5.4-13.9	12.9- 24.1	10.1- 22.3
Basement complex	149	0.0- 1.5	4.5-12.0	12.0- 19.4	4.5- 12.0
Sediment	94	0.0- 0.9	0.9- 1.9	0.9- 4.7	5.6- 10.3

[a]Basement complex makes up the total.
[b]Interior plains make up the total.

Table 2. Wetlands in tropical subsaharan Africa (12.2 million km²).

Category	Area '000s km²	% of total wetlands	% of total area
Coastal wetlands	165[a]	7	1.5
Inland basins	1075[a]	45	9.0
River floodplains	300[a]	12	2.5
Inland valleys	850[b]	36	7.0

[a]Figure was calculated from FAO 1977.
[b]Figure was estimated from data for West Africa (Hekstra and Andriesse 1983).

The Kaduna river floodplains are part of the vast area suitable for rice cultivation in subsaharan Africa. This area is traditionally ridged and planted by local farmers; it is flooded for most of the growing season.

The study area comprised the guinea savanna zone and the equatorial forest, corresponding more or less to the subhumid and humid tropics of West Africa. The entire area covers 2.2 million km^2.

Based on geomorphologic and geologic differences, the inventory area was divided into four land regions. These are broad landscapes with recurrent physiography. They are the coastal plains (covering about 5% of the study area), the interior plains (50%), the plateaus (30%), and the highlands (15%). Lithologically the main differentiation in West Africa is basement complex, covering some 65% of the area; "older" sedimentary rocks (20%), Quaternary sediments (10%), and Cretaceous and younger volcanic rocks (5%).

To reflect the project's emphasis (smallholder farming), I focused on the occurrence and distribution of the inland valleys. Because they are small, they seem most appropriate for research implementation. Based on the interpretation of soil maps and land system maps of the various countries in the study area, ranging in scale from 1:100.000 to 1:500.000, I found that stream-flow valleys and river-overflow valleys constitute a remarkably high proportion of the inventory area (Table 1): about 4–10% each. In total they cover an area between 200 000 and 400 000 km^2. River floodplains were estimated to occupy 2.5–6% of the area (50 000–130 000 km^2), and the total area of coastal wetlands and inland basins combined is 40 000–75 000 km^2 (2–3.5%).

To determine the wetlands in tropical subsaharan Africa, I consulted the soil map of Africa (FAO 1977) and estimated the areas

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for inland valleys, extrapolating conservatively the data obtained for West Africa (Table 2). The results were crosschecked with data from soil surveys in various central and east African countries. Nevertheless they should be used with care.

I found that even conservatively estimated, the "smallest"

Table 3. Suitability rating, kind of drainage problem and extent of soils with impeded drainage in Africa, excluding the aridic zone (van Dam and van Diepen 1982).

Sym-bol	Soil unit	Area ('000s km²)	Main drainage problem		Suitability for wet-land rice[a]
			Flooding	Ponding	
Bg	Gleyic Cambisol	0.3		x	1
Bv	Vertic Cambisol	18.5		x	2p
G	Gleysol, undiff.	45.3	x		—
Gd	Dystric Gleysol	96.1	x		2n
Ge	Eutric Gleysol	220.7	x		1
Gh	Humic Gleysol	123.3	x		2n
Gm	Mollic Gleysol	27.7	x		1
Gp	Plinthic Gleysol	14.9	x		2n
J	Fluvisol, undiff.	35.5	x		—
Jc	Calcaric Fluvisol	36.8	x		1
Jd	Dystric Fluvisol	23.3	x		2n
Je	Eutric Fluvisol	269.1	x		1
Jt	Thionic Fluvisol	37.2	x		2j
Lg	Gleyic Luvisol	100.0		x	1
Od	Dystric Histosol	4.6	x	x	4*AN*
Oe	Eutric Histosol	12.3	x	x	3*A*
Ph	Humic Podzols	20.6		x	4*MN*
Qa	Albic Arenosol	9.5	x	x	4*MN*
Ql	Luvic Arenosol	5.5	x	x	4M*N*
Rd	Dystric Regosol	10.1		x	4MN
Re	Eutric Regosol	7.5		x	4*M*N
So	Orthic Solonetz	19.7		x	3np*Z*
V	Vertisol, undiff.	17.9		x	—
Vp	Pellic Vertisol	300.6		x	2P
W	Planosol, undiff.	7.2		x	—
We	Eutric Planosol	39.9		x	2a
Ws	Solodic Planosol	21.0		x	3ANZ
Z	Solonchak, undiff.	9.3		x	—
Zg	Gleyic Solonchak	2.0		x	2nZ
Zo	Orthic Solonchak	5.2		x	2nZ

[a]Suitability: high = 1; moderate = 2; low = 3; not suitable = 4; limitations: bearing capacity = a; toxicity/acidity = j; permeability = m; nutrient availability = n; workability = p; and salinity/alkalinity = z; severity of limitations: lower case letters = slight; upper case letters = moderate; italicized upper case letters = severe.

wetlands occupy the second largest total area: 850 000 km^2. This large area warrants research aimed at alleviating the physical constraints to development: flooding and nutrient availability.

In the large wetlands distinguishable on FAO's soil map, the Fluvisols and Gleysols, the main soils in deltas, estuaries, tidal flats, and river floodplains are subject to flooding mainly, whereas most of the other soils have impeded drainage because of high water tables (Table 3).

Classification of the soils

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Abstract *Wetland, as distinguishable from dryland and from open water, has free water at or on the surface for about 2 months or more of a growing season. The water is shallow enough to allow the growth of vegetation rooted in the soil. Soil classification systems do not deal with wetland soils but with hydromorphic soils. There are differences between the two concepts that have practical implications.*

Of the soil classification systems applicable worldwide, the Legend *of the FAO–Unesco soil map of the world (FAO 1974) is designed for exploratory or reconnaissance work.* Soil Taxonomy *(Soil Conservation Service 1975) can be used from exploratory to detailed scales.*

Soil Taxonomy *recognizes hydromorphic soils at the suborder level (mainly wetland soils), and soils with hydromorphism in some horizons at the subgroup level (mostly dryland, some wetland soils). The concept of an aquic moisture regime is used in the classification, denoting water saturation that has led to defined signs of reduction. There are recent proposals to widen and subdivide the aquic moisture regime to allow the distinction of saturation by groundwater or surface water, natural or artificial, and of saturation by water not causing soil reduction.*

Even with these improvements, the system does not satisfy the classification needs of researchers or farmers who work with wetland, not just with wetland soils. Classification should therefore deal with four main aspects of wetland: soil characteristics, climatic and weather variables, soil-moisture regimes, and surface-water regimes. The work already done on each of these aspects could be integrated into a form useful for research and for transfer of the results to farmers' environments.

Wetland soils may be mineral or organic. Some wetland areas, especially the seasonally dry ones, have mineral soils, without or with a thin peat cover. Other wetland areas, particularly the perennially wet ones, have deep peat soils in their centres, grading through shallow peat into a band of seasonally dry mineral wetland soils adjacent to dryland. This paper deals mainly with mineral wetland soils.

Most mineral wetland soils are in alluvial material: fluvial, lacustrine, estuarine, or marine; few are in residual parent material.

Wetland soils are extremely variable. They range from soft, semiliquid, massive and structureless or laminated in perennially submerged conditions to consolidated, firm, with a blocky or prismatic structure, e.g., in seasonally dry environments. Textures range from clays to sands. Soil profiles range from undeveloped to strongly developed.

The material of peat soils normally accumulates in wetland conditions; the parent materials and the characteristics of mineral soils in wetlands may or may not be related to the present wetland conditions. The characteristics of mineral wetland soils depend on their past history, including any periods in which they have developed above a water table. The processes currently taking place in these soils are determined by these characteristics and by the perennially or periodically water-saturated or flooded conditions.

Wetland conditions occur for two general reasons: because the groundwater is seasonally or perennially at or above the soil surface or because surface water, from precipitation or run-on, cannot be removed as fast as it arrives. Surface water is retained on level ground or in depressions because of a slow hydraulic conductivity of the soil, or of a soil horizon or the substratum: for example, a traffic pan, a strongly developed illuvial horizon, or slowly permeable rock.

WETLAND DEFINED; SEASONAL DIFFERENCES

Several definitions of wetland exist, mainly referring to natural ecologic environments. The following definition is an attempt to serve the needs of agriculture and at the same time maintain practical and sensible boundaries to natural wetlands.

Wetland, as a part of the earth's surface, is distinguishable from dryland and from open water. It has free water at or on the surface for at least the major part of the growing season of arable crops, or for at least 2 months of the growing season of perennial crops, grassland, forest, or other vegetation. The water is sufficiently shallow to allow the growth of a wetland crop or of natural vegetation rooted in the soil.

Free water may occur naturally, as in many floodplains and valleys in humid climates; it may also be retained by field bunds, puddled plow layers, or traffic pans from rainfall, run-on, or irrigation sources.

Wetland as defined here has at least one wet growing season but may be dry or moist, without surface water, in other seasons. Wetland soils may therefore alternately support wetland and dryland crops and in fact normally do when cultivated.

Dryland comprises land without surface water or water saturation to the soil surface for a significant part of the growing season. It may be bunded or unbunded and may have seasonal or (rarely) perennial water saturation in deeper horizons. Dryland may also be intermittently water-saturated in the surface horizon for periods long enough to cause reduction.

The boundary between wetland and dryland is often gradual, not as clear as people would like to draw it. Such cases occur, e.g., on the lower slopes of inland valleys as studied by Veldkamp (1979). The hydromorphic riceland along the middle to low portions of the slope is intermittently saturated and loses large quantities of nitrogen by denitrification: this appears to be dryland. The lowest part of the slope, less than about a metre above the valley bottom, is wetland as shown by the measured groundwater levels during several seasons. The boundary between the two fluctuates from year to year, depending on variations in rainfall.

HYDROLOGY AND DYNAMICS OF WETLAND SOILS

A major distinction was traditionally made between the concepts of groundwater gley ("true" gley) soils and surface-water gley ("pseudogley") soils by, e.g., German, French, and British soil scientists. The term "gley", meaning water-saturated mud, was introduced into soil science by Russian pedologists.

In groundwater gley soils, the deep soil horizons are permanently under the groundwater table and are completely reduced, being gray or greenish or bluish gray. Horizons closer to the soil surface may be gray mottled with brownish or reddish iron oxides and in some cases, still higher, mottled with black, mixed iron-manganese oxides.

In surface-water gley soils, water saturation occurs periodically in surface or near-surface horizons by the combination of seasons with high rainfall; a low hydraulic conductivity of lower soil horizons; a level, nearly level, or depressional land surface; and in some cases run-on or lateral seepage through the surface horizons. Deeper horizons are less affected by periodic reduction or may be permanently oxidized. There is no permanent groundwater within the depth of the soil profile.

In many cases this distinction corresponds with one between chemically rich and poor soils. Groundwater gley soils are mostly formed in recent sediments, where leaching is often very slow. Some are enriched by groundwater from adjacent higher areas bringing in basic cations and dissolved silica. However, some groundwater gley soils are extremely poor in nutrients — for example, where upwelling groundwater is acid and has a low electrolyte content, as in narrow valleys draining acid uplands in southern Sri Lanka or parts of West Africa, for example.

Surface-water gley soils tend to occur on terraces — old, often late Pleistocene, level or nearly level landforms. Millennia of leaching under reduced conditions in the wet season, alternating with oxidation in the dry season, have reduced the clay content, cation exchange capacity, and base saturation in the surface and near-surface horizons. They are particularly extensive in humid tropical climates with a dry season.

Some of the groundwater gley soils in which the permanently reduced horizon occurs at a fairly great depth have near-surface horizons that are subject to periodic saturation, reduction, and leaching by rainwater during the wet season, alternating with oxidation during the dry season. These soils then combine the features of surface-water gley soils and groundwater gley soils: acid upper horizons with low contents of clay and nutrients, and a permanently reduced substratum.

One form of surface-water gley soil is not impoverished by leaching: a variant called stagnogley. This has an extremely low hydraulic conductivity in the subsoil or substratum so that vertical leaching is virtually absent. Such soils occur in level sites or slight depressions often on terraces. Seasonal saturation is by essentially stagnant water and generally causes strong reduction in the upper horizons. The water is removed slowly, partly by evapotranspiration during the dry season and partly by flow over the soil surface (if the depression is not completely closed).

Clearly, a simple classification on the basis of the origin of the saturating water does not adequately cover the gley soils. Morphologic and chemical data reflecting their nutrient dynamics should be considered in their classification as well.

CHOICE OF SOIL CLASSIFICATION SYSTEMS

No system of soil classification formally defines a wetland soil or an equivalent concept. Instead, most systems distinguish classes of hydromorphic soils, i.e., soils with defined signs of periodically or permanently reduced conditions. They do not distinguish classes of wetland soils, i.e., soils that are periodically or perennially water-saturated or flooded. The difference between the two concepts seems small but is of practical importance.

In the FAO-Unesco *Legend* for the soil map of the world (FAO 1974), the Gleysols, Fluvisols, Planosols, and Histosols make up most of the wetland soils, although gleyic units of, for example, Acrisols, Luvisols, or Podzols are also mostly wetland soils. The Plinthosols, newly defined in the 1985 draft of the revised *Legend*, have been separated from the Ferralsols because they have plinthite that causes surface-water flooding and waterlogging.

In *Soil Taxonomy* (Soil Conservation Service 1975), soils with an aquic moisture regime and specified morphologic characteristics of wetness are distinguished at the suborder level. Aquic subgroups generally are not wetland soils but have signs of wetness only in lower horizons. Moormann (1978) has discussed the aspects of *Soil Taxonomy* relevant to wetland rice soils.

In China, where wetland is extensive, particularly in a broad band along the Yangtze river and further south, wetland soils are equated to hydromorphic soils (Gong 1984). Gong distinguishes the hydromorphic soils at order level. At suborder level they are split into bog soils, which are naturally wet, and paddy soils, in which the hydrologic conditions have been changed by human action. Great groups are broadly distinguished by their material nature: salt-affected, acid sulfate, carbonated, siallitic, and allitic. Subgroups of the bog soils indicate the drainage conditions and the presence or absence of peat. The paddy soils are seasonally oxidized at least in the surface horizon. Three subgroups of the paddy soils indicate the redox conditions in the deeper horizons; one indicates bleaching (impoverishment). Several older classifications of paddy soils appear to be in use by different groups; these were quoted and compared earlier by Gong (1981).

The distinction between naturally wet soils and paddy soils, modified by humans, is a strong point in these classifications. Recognition of an anthraquic horizon, proposed by Moormann (1978) for inclusion in *Soil Taxonomy*, would serve a similar purpose.

The European classification systems generally distinguish two main kinds of wetland soils with different hydrologic conditions at the highest categorical level: groundwater gley (or "true" gley) and surface-water gley (or pseudogley) soils. This is a useful distinction, but the European systems are generally designed for national use rather than for a wide range of environments.

The French system (CPCS 1967) is multicategorical. Taxa of the four highest levels (class, subclass, group, and subgroup) are described; ways of distinguishing the lower-level categories are indicated. Each class is characterized by a major soil-forming process or by a combination of processes. The class of hydromorphic soils comprises all soils in which the dominant soil-forming process and the most conspicuous morphologic features are related to water saturation that causes reducing conditions in the soil. The water saturation may be temporary or perennial; it may affect all or part of the soil horizons; and it may be caused by a high groundwater table, a perched water table, or floodwater.

At the subclass level of the French system, organic and mineral hydromorphic soils are distinguished. The organic hydromorphic soils are differentiated on the basis of the decomposition stage of the organic material. The mineral hydromorphic soils consist of six groups: with (groundwater) gley; with pseudogley (surface-water gley); with stagnogley (semipermanent water saturation and reduction of upper soil horizons in high-rainfall regions); with amphigley (a combination of groundwater gley and surface-water gley); with an iron pan; and with redistributed calcium carbonate or gypsum. Hydromorphic and similar subgroups in other classes comprise soils that are not as well drained as the other subgroups but do not include all wetland soils. That is, there is no provision for wetland soils without dominant hydromorphic characteristics.

The French system is elegantly conceived, but difficult to use for the uninitiated, since most taxa are characterized by central concepts rather than delimited by quantitative, morphometric definitions.

The system proposed by a working group of the Office de la recherche scientifique et technique outre-mer (ORSTOM, Paris) (Fauck et al. 1979; English summary: Segalen et al. 1984) is designed for worldwide use. It relegates the hydromorphic soils to group and subgroup levels, where they are recognized on the basis of gley or hemigley horizons within specified depths below the A horizon. Gley and hemigley horizons are gray to bluish gray, distinguished by the presence of yellow, brown, or red mottles and the simultaneous presence of iron in reduced and oxidized forms. Gley horizons have few mottles; hemigley horizons more than 5%. Duration and depth of flooding or water saturation are not considered. Much of the classification is by central concepts rather than by definitions.

Recently, ORSTOM seems to have changed its approach to soil studies in the tropics, and classification has been relegated a small part, if any (Ruellan 1985). Indications are that the organization now plans to focus on describing soil characteristics and horizons rather than on defining whole soils in a classification system.

Many other national or individual classification systems exist, but all have drawbacks for international use. The *Legend* (FAO 1974) and *Soil Taxonomy* are the only two suitable for worldwide use.

The *Legend* is designed for use to unit (group) level, mainly for broad-scale, reconnaissance, or exploratory work. Guidelines for the definition of subunits (subgroups) may be included in the revised edition envisaged for 1986.

Soil Taxonomy is a multicategorical system, with defined criteria down to family level. This makes it applicable at widely different levels of detail. It is also supported by an organization for continual improvement through international committees, for example the international committee on classification of soils with an aquic moisture regime (ICOMAQ).

CLASSIFICATION OF HYDROMORPHIC SOILS IN *SOIL TAXONOMY*

SUBORDERS

Hydromorphic soils are distinguished from soils with free internal drainage at the suborder level in *Soil Taxonomy*. The soils in the aquic suborders — e.g., Aquepts, Aqualfs — are gray or greenish or bluish gray (caused by continuously reduced conditions) or are mottled with contrasting colours caused by alternating reduced and oxidized conditions. In 5 of the 10 soil orders, soils in the aquic suborders should also have an aquic soil-moisture regime or be artificially drained. In most cases this is explicit; for the Aquents, it is clearly implied.

In the aquic moisture regime, the soil or certain horizons are periodically reduced because of saturation by groundwater or by water of the capillary fringe. The water should be stagnant, as estimated from the persistence of the colour from a dye added to the water in an unlined borehole. The requirement of reduction implies that temperatures should be above about 5°C and that some organic matter should be present.

Three orders — the Aridisols, Histosols, and Vertisols — do not have aquic suborders. Essentially, all Aridisols are dryland soils and virtually all Histosols are wetland soils; they are subdivided by the degree of decomposition of the organic material. Vertisols are a special case, discussed in the next section.

In the other two orders — Oxisols and Ultisols — an aquic soil-moisture regime is not mentioned for the aquic suborders but is implicit in the Aquults, which are described as having groundwater very close to the surface during part of each year. The soils in the suborder Aquox may or may not have an aquic moisture regime; they are described as commonly flooded during the rainy season or occurring at the base of slopes where they receive seepage water.

SUBGROUPS

In *Soil Taxonomy*, hydromorphic characteristics are not considered at the group level; the next level down from suborders in the hierarchy is subgroups. Aquic subgroups are distinguished on the basis of temporary saturation by water in part of the solum, generally — but not always — in combination with soil colours reflecting periodic reduction and oxidation. At the subgroup level, the origin of the water saturation, i.e., surface flooding or groundwater, generally remains unspecified, but the description of most subgroups indicates clearly that saturation from a temporarily high groundwater is meant. Aquic subgroups occur in all soil orders except in the Histosols. Most of the soils in aquic subgroups are dryland soils, albeit with imperfect drainage.

Epiaquic subgroups are recognized in the Oxisol and Ultisol orders. Soils in the epiaquic subgroups are water-saturated in the surface horizons because of temporary flooding or seasonally heavy rainfall and have colours that become redder with depth. Generally, the colour in the upper horizons approaches but does not fit the grays (low chroma) defined for the aquic suborders, which indicates that the periodic reduction is not severe. The epiaquic subgroups comprise mostly wetland soils.

This summary description indicates that internal soil features related to high levels of groundwater, now or in the recent past, are the primary criteria used to place soils into "wet" classes of *Soil Taxonomy.* Flooding or periodic saturation by surface water is taken into consideration only if it has brought about grayish colours and mottles, and only then in a few groups. Even within this conceptual framework, there are probably epiaquic subgroups in many more soil groups than the few recognized in *Soil Taxonomy.*

In spite of its implicit use in the epiaquic subgroups, the epiaquic soil-moisture regime has not been defined or described in *Soil Taxonomy.* It would be a useful addition to the descriptions of the aquic and peraquic moisture regimes.

WETLAND IN CRACKING CLAY

Water saturation in Vertisols is always a surface feature (Blokhuis 1982). In flooded Vertisols, only the surface horizon and the parts of deeper horizons adjoining cracks, particularly near the bottom of cracks, are water-saturated for part of the year. There are also other cracking clay soils that have a very irregular boundary between water-saturated and dry or moist parts of the soil (Bouma et al. 1980).

At one time, pellic groups of the Vertisols were thought to owe their gray colours to reducing conditions, but this conception has been criticized on three counts. Not all flooded Vertisols are pellic. Some pellic Vertisols are not subject to flooding. Even when reducing conditions exist in the pellic Vertisols, they are never permanent, and seasonal reduction would be expected to lead to mottling rather than to uniformly gray soils.

Aquic subgroups have been defined in the Chromoxererts and the Chromuderts. These subgroups have distinct or prominent mottles in the upper 0.5 m of the soil. No aquic subgroups have been distinguished in the Pelloxererts and the Pelluderts, although hydromorphism is generally stronger in pellic than in chromic groups.

The international committee on the classification of Vertisols (ICOMERT) has proposed that the concept of the aquic soil-moisture regime be widened to include saturation by surface water (Comerma 1985). The term epiaquic, as used in the relevant subgroups of the Oxisols and Ultisols, would be more appropriate than aquic for periodic surface-water saturation.

AQUIC MOISTURE REGIME: RECENT DEVELOPMENTS

Soils with an aquic moisture regime, as defined in *Soil Taxonomy*, are periodically reduced because of saturation by groundwater or water of the capillary fringe. The water is virtually stagnant as indicated by the persistence of colour after addition of a dye to water standing in an unlined borehole.

There are exceptions to the requirement that saturation is caused by (true) groundwater. In some cases, the water-saturated conditions are brought about by water stagnating on an impervious layer or horizon. Examples are the groups of the Albaqualfs, Fragiaqualfs, and Natraqualfs, and part of the Aquods suborder. In these soils, there need not be water saturation in the soil horizons below an argillic horizon, a duripan (indurated horizon), a fragipan (dense, brittle horizon), or a placic horizon (thin iron pan).

The peraquic moisture regime is defined similarly, but the water saturation and the reducing conditions are perennial rather than periodic. The peraquic moisture regime is not a criterion in soil classification at present but serves to describe certain soils classified on the basis of other criteria.

The definition of the aquic moisture regime has been a major topic in the discussions of ICOMAQ. One suggestion (Moormann 1984) was to broaden the definition in such a way as to include all soils subject to prolonged wetness and reduction in horizons less than, for example, 1 m from the surface. The aquic moisture regime, thus redefined, could have one of the following forms:

- Orthaquic: true groundwater gley soils (the aquic moisture regime as defined in *Soil Taxonomy*);
- Peraquic: as defined in *Soil Taxonomy*;
- Endoaquic: wetness and reduction by groundwater only in the lower horizons (criterion for aquic subgroups);

- Epiaquic: wetness and reduction only in the surface horizons (the definition differs from the one for epiaquic subgroups in *Soil Taxonomy*);
- Anthraquic: as epiaquic, but resulting from artificial ponding in wetland fields.

In Moormann's concept of the aquic moisture regime there is still no provision for soils in which wetness has not led to reducing conditions (Moormann and van de Wetering 1985). Groundwater may contain considerable dissolved oxygen, e.g., in tropical areas with moderate relief and lateral water flow in the soil, so that the morphologic characteristics of the soil do not reflect the wetness. Also, the lack of reducing microorganisms in some saline waterlogged desert soils prevents the development of reducing conditions, and, in others, the lack of (readily decomposable) organic matter, in combination with high levels of calcium carbonate, inhibits reduction. In Nigeria, Veldkamp (1979) found that, in many cases, mottling could not be related to the length of the periods of water saturation.

In the second ICOMAQ circular letter (ICOMAQ 1985), Buol criticized the statement in *Soil Taxonomy* that an aquic moisture regime must be a reducing one. He mentioned several cases where this is not so and pleaded for the recognition of an aquic moisture regime that is not reducing: oxyaquic.

Buol also suggested that any soil condition that has to be maintained by an expenditure of energy by humans should be recognized in the lowest category or even outside the taxonomy. He considers placement of soils with hydromorphic properties induced by wetland crop cultivation in "extragrade" subgroups to be in line with the rationale for extragrades. However, the creation of "padiaquic" families is preferable in his opinion if a uniform criterion could be devised to distinguish them across all subgroups in which they occur.

Moormann and van de Wetering (1985) suggest that a special provision be made in *Soil Taxonomy* for soils that have an aquic (orthaquic or epiaquic) moisture regime in the wet season, but an ustic moisture regime in the dry season (part of the subsoil dry for at least 3 months), tentatively labeled an ustaquic regime. This has met with a mixed reception in ICOMAQ, but it raises an important issue.

Many wetland soils are used for a wetland crop and for a dryland crop in alternate seasons, so it is not only the degree of wetness of the soil and the period of water saturation, but also the nature of the wetland-dryland and dryland-wetland transitions that are important to the farmer, as well as the moisture conditions in the dryland season. A classification of moisture conditions that neglects the dryland season of a wetland soil is incomplete for practical purposes.

CLASSIFICATION OF WETLAND SOILS OR ECOLOGIC SYSTEMS

Wetland, a wetland site, or a wetland ecology comprises more than a wetland soil. Even under the most optimistic assumptions about developments in soil classification, the necessary distinctions in surface-water hydrology or landform or slope, for example, cannot be expected to be adequately covered by definitions of soil taxa.

An agronomist or a farmer uses a wetland site or a wetland area, not just a wetland soil. Classification efforts should not be restricted to soils alone, therefore, but should deal with four important aspects in the case of arable use, and five in other cases. These aspects are soil characteristics; climatic and weather variables; soil-moisture regime; surface-water regime; and vegetation or crop in the case of a perennial crop or plant cover.

The morphologic characteristics of the soil as well as the fertility, chemical, hydrologic, physical, and mineralogic characteristics are at least partly covered by present soil-classification systems. Temperature and other climatic and weather variables are normally classified and mapped independently of the soils, but some aspects of the temperature regime have been used in the definition of soil taxa. A separate classification of soil fertility aspects, as discussed by Kyuma et al. (elsewhere in this volume), may be useful in some cases.

Soil-moisture regime is partly covered by the definitions in *Soil Taxonomy* with later revisions. Van Diepen (1985), referring to the lack of correspondence between soil wetness and soil-moisture regimes, called for an independent classification of soil wetness. What is required goes beyond the terms of reference of ICOMAQ,which refers to moisture in the soil rather than to the hydrologic conditions on the surface. Van Diepen recommends the use of hydrographs to show the fluctuations of water levels above or below the surface with time. Such hydrographs have been used, for example, in Sierra Leone (Odell et al. 1974). The data thus obtained would still not take into account the zone above the groundwater level that is saturated by capillary rise.

The researcher on wetland needs further information on the moisture in the soil, e.g., the direction of flow or the chemistry of the soil solution in the case of upwelling or interflow (lateral flow).

The surface-water regime in wetland areas used for rice has been dealt with in several classification efforts, summarized by Garrity (1984). The latest proposed classification of rice environments, on the basis of discussions and correspondence between members of a large international committee (Khush 1984), is primarily based on surface-water regime.

The classification recognizes irrigated (wetland) rice environments; rainfed lowland (wetland) rice environments, subdivided by water depth into shallow (<25 cm), medium deep (25-50 cm), deep (50 cm-1 m), and very deep (>1 m) environments; and tidal wetlands. The tidal wetlands are subdivided into wetlands with perennially fresh, seasonally saline, and perennially saline water. The rainfed lowland is further subdivided by the absence or presence of drought or submergence hazards or water stagnation associated with low yields of rice.

This classification covers most aspects of the surface-water regime. A few further subdivisions may need to be recognized, on the basis of rapid or irregular rise of flood level; rapid overland flow of floodwater; sediment-laden vs. clear floodwater where this distinction influences rates of photosynthesis, i.e., in deepwater areas; the presence of toxins such as Al or Fe in the surface water originating from acid sulfate areas or borate ions from volcanic materials; and low temperatures of water, as in parts of China.

Soil classification by itself is only one wheel of the cart. Once soil-classification information is integrated in a data structure embracing soils, climate, soil-moisture regime, and surface-water regime, it can be used effectively for the planning of experiments on wetland and for the transfer of research results to farmers' fields.

We thank A.C. Van Diepen for his suggestions, which we used in this paper.

Evaluation of the fertility of the soils

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Abstract *In the traditional rice-growing countries in Asia, various systems of evaluating rice soils have been developed. They reflect widely different land conditions and cultivation practices. A recently developed system for fertility capability classification (FCC) as adapted to the wetland condition is useful in converting the soil survey information and soil test data to the items of soil evaluation. Also, a numerical method developed for the evaluation of fertility components, i.e., inherent potentiality, nitrogen supply capacity, and phosphate supply potential, of rice soils is a promising tool for Africa, having already proved useful for evaluation of tropical Asian paddy soils. The FCC system and the numerical method have been applied to 71 West African wetland soils. The results indicate that the soils are generally infertile. Particularly low was the inherent potentiality of the soils from the humid region.*

Most of the soils suitable for rice occur in the "aquic" lowlands or wetlands and, if cultivated, are used solely for rice under natural or artificial submergence. Under such conditions, the priority of considerations relevant to crop production is soil fertility; water relations are only of secondary importance as long as enough water for submergence is available. Even the workability of clayey soils that prevail in lowlands is improved under submergence.

Generally, soil in the lowlands is easier to keep fertile and stable than that in the uplands. Nitrogen can be supplied more abundantly by biological fixation, phosphorus can be made more readily available under a reduced condition, and potassium and other bases can be supplied by water. More importantly, in the lowlands, there is no worry of erosion.

Being in the lowlands, rice soils are by and large underdeveloped in terms of pedogenesis, and this condition means that parent materials are particularly important in evaluations of soil fertility. Parent materials are directly reflected in the fertility of rice soils, and the variation in parent materials is wider in the tropics than elsewhere.

In this paper a few methods of fertility evaluation for rice soils are introduced and discussed, and then a preliminary application of some of these methods to the West African soils is attempted.

QUALITATIVE METHODS

Several traditional rice-growing countries in Asia have attempted to establish systems by which the capability of soils to support lowland rice can be assessed. For example, in Japan a classification system for soil capability was developed in 1964 (Secretariat of the Technological Council for Agriculture, Forestry, and Fisheries 1964) and has been used ever since.

JAPAN

In Japan, the soil capacity is assessed by a grading system, in which I is most capable (no limitation), II is less capable (some limitations), III is least capable (severe limitations), and IV is incapable of growing lowland rice. In this system the soils are evaluated for:

1. Thickness of the plow layer (t);
2. Effective depth of the solum (d);
3. Gravel content of the plow layer (g);
4. Permeability under submergence (l), as judged by:
    a) subsoil texture, and
    b) subsoil compactness;
5. Redox property (r), as judged by:
    a) readily decomposable organic matter in the plow layer,
    b) free iron oxides in the plow layer, and
    c) degree of gleying;
6. Inherent fertility (f), as judged by:
    a) cation exchange capacity,
    b) phosphate fixation, and
    c) base saturation and pH;
7. Nutrient level (n), as judged by:
    a) NH_4-N upon air drying,
    b) Truog's available P_2O_5,
    c) exchangeable K_2O,
    d) exchangeable CaO or Ca saturation,

e) exchangeable MgO,
f) available SiO_2 (acetate buffer pH 4),
g) microelements (B, Mn, etc.), and
h) acidity, pH (H_2O) or exchange acidity (Y_1);

8. Toxic substances (h), as judged by:
   a) sulfur compounds,
   b) salt (salinity judged by Cl^-),
   c) heavy metals (Cr, Ni, Cu, Zn, As, etc.), and
   d) irrigation water (temperature, pH, total N, salts, heavy metals);
9. Disasters (a), as judged by the records of:
   a) flash floods, and
   b) landslides.

Almost all the rice soils in Japan are irrigated so water availability is not included among the items of evaluation. The final soil capability class is expressed by a simplified formula, such as III d II trn, or simply III, taking the lowest grade given to an item. The Japanese system has been applied primarily to the established rice soils as the basis of soil amelioration, and more than 95% of the soils have been rated either as class II or III, indicating the need for some improvement.

THAILAND

In Thailand, also, a system of classification exists; it was developed by Robinson and Steele (1972) for lowland rice (or paddy) cultivation. Soils are divided into five groups:

- Group P-I: soils very well suited for paddy, with no significant limitations. In general this group includes soils that are moderately deep, fine textured, slowly permeable, nearly level, and naturally somewhat poorly to poorly drained. They are high or moderately high in fertility and do not have salts or toxic substances in harmful quantities. Water can be impounded easily on these soils and water supply is sufficient for at least one high-yielding crop a year, without risk of damage by drought or rapid flooding.
- Group P-II: soils well suited for paddy, with slight limitations. Limitations are few; they include one or more of the following: somewhat unfavourable texture, salinity or acidity that reduces yields slightly, slight risk of damage by water shortage or rapid floods.
- Group P-III: soils moderately well suited for paddy, with moderate limitations. Soils in P-III have the same kinds of limitations as those in class P-II, but the degree of limitation is somewhat greater. Additional limitations that may occur are gentle slopes and distinct microrelief.
- Group P-IV: soils poorly suited for paddy with severe hazards

Table 1. Guidelines for grouping soils in classes for paddy: limitations and suitability.

Soil limiting factor	Suitability class				
	PI	PII	PIII	PIV	PV
Depth (cm)	>50	>50	>25	>25	—
Texture of surface	Clay, silty clay, clay loam, silty clay loam, sandy clay	Clay, silty clay, clay loam, silty clay loam, sandy clay, sandy clay loam	Sandy loam to clay	Loamy sand to clay	—
Permeability of subsoil (cm/h)	<0.5, slow	<1.5, slow to moderate	<5, slow to moderate	<15, slow to rapid	—
Fertility	High	Moderate to high	Moderately low to high	Low to high	—
pH (1:1 dry soil, H_2O)	5.0-7.5	4.5-8.0	4.0-8.0	3.5-8.5	—
Salinity (EC 5 × 10^6)	<1500	<2500	<2500	<4000	—
Slope (%)	<1	<2	<3	<5	—
Smooth land (% of total)	>80	>80	>50	>40	—
Leveling required	Little	Little	Moderate	Much	—
Stones that hinder crops	Nil	Nil to slightly gravelly	Nil to slightly gravelly, stony	Nil to slightly gravelly, stony	—
Damage risk from: Drought	Nil	Slight	Moderate in <4 of 10 years	Severe in <6 of 10 years	—
Flooding or saline	Slight in <1 of 10 years	Moderate in <3 of 10 years	Severe in <4 of 10 years	Severe in <6 of 10 years	—
Drainage	Somewhat poor to poor	Somewhat poor to poor	Somewhat poor to very poor	Well to very poor	—

or limitations. Commonly the soils are limited by one or more of the following: shallowness, unfavourable texture, moderately rapid permeability, low fertility, salinity or acidity that reduces yields sharply, high risk of damage from water shortage or rapid floods, and moderate slopes or microrelief that make it difficult to impound water.

- Group P-V: soils generally not suited for paddy land. These soils have very severe limitations, impossible or impractical to correct, that make them unsuited for wetland rice.

The limiting factors and the criteria are given for evaluation at the group level (Table 1).

The groups are divided into subgroups, with the major limiting factor indicated by a symbol, for example P-IIIa. All soils having the same major limiting factor can be placed in a subgroup. The symbols used in Thailand for limiting factors are:

s Soil limitation in the root zone — features such as shallowness, unfavourable texture, stoniness, and low fertility;
m Lack of moisture for plant growth — insufficient rainfall, low capacity for water storage, or unfavourable topographic position;
t Unfavourable topography — high topographic position or distinct microrelief that limits use;
f Flooding — susceptibility to flash floods or excessively deep flooding, which damage the crop;
x Excessive salinity or alkalinity;
a Excessive acidity — high total acidity, difficult to correct, as in acid sulfate soils; and
d Unfavourable internal drainage — either very slow drainage allowing toxic chemicals to accumulate or very rapid drainage making it difficult to impound water on the surface.

FERTILITY CAPABILITY CLASSIFICATION (FCC)

Recently Sanchez and Buol (1985) proposed an agronomic taxonomy for wetland soils, which is an extension of their fertility capability classification (FCC) system developed for upland soils. FCC is a technical system for grouping soils according to the kinds of problems they present for agronomic management of their chemical and physical properties (Buol et al. 1975). It is based on quantitative soil parameters relevant to plant growth, mostly derived from class limits of *Soil Taxonomy* (Soil Conservation Service 1975) or of the *Legend* of the FAO-Unesco soil map of the world (FAO 1974).

In the latest FCC version (Sanchez et al. 1982), the soils are classified according to whether a characteristic is present or not (Table 2). The FCC unit then lists the type and substrata type (if

Table 2. The fertility capability classification (FCC) system in which the type and substrata type (if present) of the soils are listed in upper-case letters and the modifiers are in lower-case letters, with the gravel modifier being either ′ or ″. The slope can be placed in parentheses as the final element.

LEVEL/ Symbol	Meaning	Description
TYPE	Topsoil	Texture of plow layer or top 20 cm, whichever is shallower
S	Sandy	Loamy sands and sands (as defined by USDA)
L	Loamy	<35% clay but not loamy sand or sand
C	Clayey	>35% clay
O	Organic	<20% organic matter to a depth of 50 cm or more
SUB-STRATA TYPE	Subsoil	Texture of subsoils when there is a marked change in texture from the surface or when a hard layer is encountered within 50 cm of surface
S	Sandy	Loamy sands and sands (as defined by USDA)
L	Loamy	<35% clay but not loamy sand or sand
C	Clayey	>35% clay
R	Rock	Hard layer restricting root growth
MODIFIER[a]		
g	Gley	Soil or mottles <2 chroma within 60 cm of the surface and below all A1 horizons, or soil saturated with water for >60 days in most years
d	Dry	Ustic, aridic, or xeric soil moisture regimes (subsoil dry >90 cumulative days/year within 20-60 cm deep)
k	Low K reserves	<10% weatherable minerals in silt and sand fraction within 50 cm of the soil surface, or exchangeable K<0.20 meq/100 g or K<2% of sum of bases if bases <10 meq/100 g
e	Low cation exchange capacity of the topsoil	Within the plow layer or top 20 cm (whichever is shallower), CEC<4 meq/100 g by sum of bases + KCl — extractable Al (effective CEC) or CEC<7 meq/100 g soil by sum of cations at pH 7, or CEC<10 meq/100 g soil by sum of cations + Al + H at pH 8.2
a	Aluminum toxicity	Within the top 50 cm of soil, >60% Al saturation of the effective CEC or >67% acidity saturation of CEC by sum of cations at pH 7 or >86% acidity saturation of CEC by sum of cations at pH 8.2
h	Acidic	10-60% Al saturation of the effective CEC within 50 cm of the soil surface or pH in 1:1 H_2O between 5.0 and 6.0
b	Basic	Free $CaCO_3$ within 50 cm of soil surface (effervescence with HCl) or pH>7.3

continued

Table 2. continued

LEVEL/ Symbol	Meaning	Description
i	High fixation of P by iron	% free Fe_2O_3/% clay >0.15 and more than 35% clay, or hues of 7.5 YR or redder and granular structure. This modifier is used only in clay (C) types; it applies only to plow layer or surface 20 cm, whichever is shallower
x	X-ray amorphous	pH>10 in 1N NaF[b] or positive to field NaF test, or other indirect evidence of allophane dominance in the clay fraction
v	Vertisol	Very sticky plastic clay (>50% of 2:1 expanding clays in soils that are >35% clay) or severely shrinking and swelling topsoil
s	Salinity	>mmhos/cm of electrical conductivity of saturated extract at 25°C within 1 m of the soil surface
n	Natric	>15% Na saturation of CEC within 50 cm of the soil surface
c	Cat clay	pH<3.5 in 1:1 H_2O after being dried and jarosite mottles with hues of 2.5 Y or yellower and chromas 6 or more are present within 60 cm of the soil surface
′	Gravel	15–35% gravel or coarser (>2 mm) particles by volume to any type or substrata type (e.g., S′L = gravelly, sand over loam; SL′ = sandy over gravelly loam)
″	Gravel	>35% gravel or coarser (>2 mm) particles by volume in any type or substrata type (e.g., LC′ = loamy over clayey skeletal, L′C″ = gravelly loam over clayey skeletal)
%	Slope	Where desirable to show slope, place the percentage in parentheses after the last condition modifier [e.g., Sb (1–6%) = uniformly sandy soil, calcareous in reaction, 1–6% slope]

[a]When more than one criterion is listed, each one is sufficient, but the first is the best; the others are included here to aid in decision-making when data are limited.

[b]10.7 is considered a better limit; the NaF solution should be carefully titrated to pH 8.2 before use.

present) in capital letters, and the modifiers in lower case letters, e.g., Sek, SLa, or LCek.

In their attempt to extend the system to wetland soils, Sanchez and Buol introduced only slight modifications. A single new condition modifier proposed was g′ for pergleyic condition. They considered that other conditions that occur in the lowland could be handled by the original system rather easily, only with a slight modification in the way of interpretation. For example, *akiochi*-inclined soils or degraded rice soils may be classified as SLgaek or LCgaek. This means that the soil capability is conditioned by lighter-textured surface soil, low CEC, low nutrient reserves, and toxic levels of aluminum. FCC can be used to describe nutrient deficiencies, toxicities, and physiologic disorders specific to rice soils; for example:

	FCC system
Deficiencies	
Zn	g′, b, O
Si	ehk, ak
Toxicities	
Fe	Ci, c, ek (with interflow from Ci upland)
H_2S	SLak, CLak (with S fertilizers)
Physiologic disorders	
Akagare I	SLek, LCek (with adjacent Ci upland)
Khaira, Hadda	b, g′b

According to Moormann and van Breemen (1978), the FCC system has two definite advantages: most data can be gathered in the field or by careful interpretation of good soil maps, and the laboratory facilities required are relatively simple. As the trial to adapt the system to the wetland condition has just been started, there must still be much to be improved before the system could be completely adapted to rice soils. But even as it is, the system is no doubt useful for evaluation of both potentially reclaimable and actually cultivated rice soils.

QUANTITATIVE METHOD

The methods cited are all qualitative in the sense that they indicate only the major constraints in the use potential of rice soils. There is another more quantitative approach to the fertility evaluation of rice soils (Kyuma and Kawaguchi 1973; Kawaguchi and Kyuma 1977). This method aims at giving a numerical rating to each soil with respect to the three components of soil fertility, that is, inherent potentiality (IP), organic matter and nitrogen status (OM), and available phosphorus status (AP). This method was developed for tropical Asian rice soils but promises to be useful in Africa as well.

From nine countries in South and Southeast Asia, 410 samples of rice soil were analyzed for various fertility characters. These samples were believed to cover rice soils that occur in the region. Later, 11 characters (Table 3) were chosen and subjected to factor analysis, one of the multivariate statistical methods. As a result three mutually independent fertility components, i.e., IP, OM, and

Table 3. Characters used by Kyuma and Kawaguchi for soil analysis.

Character number	Name	Description
1	Total C	Carbon as % of air-dried soil by Tyurin's method using wet combustion
2	Total N	Nitrogen as % of air-dried soil by Kjeldahl digestion and steam distillation
3	NH_3-N	Nitrogen in mg/100 g of air-dried soil after incubation for 2 weeks at 40° C
4	Bray-P	Phosphorus in mg P_2O_5/100 g air-dried soil, Bray-Kurtz method 2
5	Exchange-able K	Potassium in meq/100 g of air-dried soil by NH_4OAc extraction or flame photometry
6	CEC	Cation exchange capacity in meq/100 g of air-dried soil, buffered neutral N-$CaCl_2$ medium
7	Available Si	Silica in mg SiO_2/100 g air-dried soil, pH 4 HOAc extraction at 40° C
8	Total P	Phosphorus in mg P_2O_5/100 g air-dried soil, HF-H_2SO_4 or HNO_3-H_2SO_4 digestion
9	HCl-P	Phosphorus in mg P_2O_5/100 g air-dried soil, 0.2 N HCl extraction at 40° C for 5 h
10	Sand	Sum of coarse and fine sands as % of air-dried soil that is free of organic matter
11	Exchange-able Ca + Mg	Calcium and magnesium in meq/100 g air-dried soil, N-NaCl extraction, EDTA titration

AP, were extracted as the compound characters. Characteristics of the three fertility components are:

- Inherent potentiality (IP) — the soil character determined by the nature and amount of clay and base status;
- Organic matter and nitrogen status (OM) — the soil character related to the organic matter and nitrogen reserves; and
- Available phosphorus status (AP) — the soil character related to capability to supply available phosphorus.

The scores of these three fertility components were computed for each of the samples:

$$f_k = b_{1k}\,\chi_1 + b_{2k}\,\chi_2 + \ldots + b_{ik}\,\chi_i + \ldots + b_{pk}\,\chi_p$$

where b_{ik} is the factor score coefficient for the ith variable and kth factor (Table 4) and χ_i is the standardized ith variable of a sample. Since the data were log-transformed before the factor analysis, the same transformation is needed for score computation. Moreover the transformed data must further be standardized according to the mean and standard deviation vectors (Table 5). As the scores thus computed for the samples are

Table 4. Factor score coefficient matrix for three factors.

Variable	Inherent potentiality	Organic matter	Available phosphorus
Total C	-0.151	0.268	-0.078
Total N	-0.147	0.839	-0.010
NH_3-N	0.045	-0.012	0.008
Bray-P	-0.091	-0.101	0.701
Exchangeable K	0.130	0.018	-0.026
CEC	0.757	-0.132	-0.214
Available Si	-0.058	0.073	0.087
Total P	0.051	-0.025	0.084
HCl-P	-0.059	-0.033	0.278
Sand	0.028	0.012	0.004
Exchangeable Ca + Mg	0.306	-0.144	0.029

standardized with a mean of zero and a variance of unity, positive score values indicate above-average status with reference to the overall mean for the 410 sample soils, and negative values indicate below-average status.

The mean scores were computed for various regions in South and Southeast Asia (Table 6). The results indicated that IP is high in the regions where active volcanism rejuvenates the soil materials (Central and East Java, Central Luzon). In the deltaic areas where sediments from soils with more or less ustic moisture regime are deposited (Godavari-Krishna delta, Bangkok plain, Gangetic sediment area in Bangladesh, Kedah-Perlis plain in Peninsular Malaysia), IP ratings are also high. In contrast, they are low for the soils on sandy, old alluvia (northeast plateau of Thailand, central Kampuchea, Madhupur-Barind tract of Bangladesh, marginal plain of Bangladesh) and on the

Table 5. Means and standard deviations of the 11 log-transformed characters for 410 sample soils.

Variable	Mean	Standard deviation
Total C	0.044	0.297
Total N	-0.994	0.282
NH_3-N	0.731	0.425
Bray-P	0.171	0.584
Exchangeable K	-0.623	0.449
CEC	1.159	0.342
Available Si	1.195	0.515
Total P	1.775	0.429
HCl-P	0.608	0.712
Sand	1.314	0.514
Exchangeable Ca + Mg	0.993	0.484

Table 6. Mean and standard deviation (SD) of numerical ratings of three fertility components for selected regions.

COUNTRY/ region	Samples	Inherent potentiality		Organic matter		Available phosphorus	
		Mean	SD	Mean	SD	Mean	SD
INDIA							
Godavari-Krishna Delta	10	1.38	0.29	-0.73	0.47	1.11	0.95
BANGLADESH							
Ganges	15	0.33	0.35	0.04	0.82	0.90	0.50
Madhupur-Barind	9	-0.75	0.60	0.35	0.64	-0.14	0.40
Marginal	16	-0.87	0.62	0.36	0.66	-0.06	0.77
Brahmaputra	13	-0.57	0.48	-0.01	0.64	1.01	0.66
SRI LANKA							
Wet and intermediate zones	14	-1.07	0.64	0.84	1.10	-0.10	0.64
Dry zone	19	-0.10	0.76	-0.36	0.70	-0.12	0.67
THAILAND							
Northeast plateau	32	-1.18	1.27	-1.14	0.77	-0.94	0.70
Upper central plain	14	-0.04	0.76	-0.05	0.49	-0.31	0.69
Bangkok plain	24	0.53	0.64	0.24	0.66	-0.51	0.86
South	6	-0.40	0.74	0.58	0.48	-0.29	0.39
KAMPUCHEA							
Central plateau	8	-0.91	0.76	-0.60	0.94	-1.19	0.69
MALAYSIA							
Kedah-Perlis	10	0.25	0.44	1.21	0.56	0.02	0.54
East coast	10	-1.23	0.20	0.78	0.59	-0.54	0.57
INDONESIA							
Central and east Java	28	0.91	0.59	-0.29	0.53	0.10	0.81
PHILIPPINES							
Central Luzon	25	0.91	0.54	-0.10	0.41	-0.36	0.97

sediments derived from acidic rocks (wet and intermediate zones of Sri Lanka, east coast of Peninsular Malaysia).

High OM ratings are correlated with humid climatic conditions and fine sediments in the lower terrain position (Peninsular Malaysia, south Thailand, wet and intermediate zones of Sri Lanka). But most lowland soils, which are dominant in subhumid to semi-arid climatic regions, have low OM ratings.

In the areas with either acidic rocks or sandy sedimentary rocks as the parent rock of the soils (northeast plateau of Thailand, central Kampuchea, east coast of Peninsular Malaysia), AP ratings are low. They are high for the soils in the

Table 7. Class levels for potentiality of fertility components.

Class no.	Limits	Potentiality
1	>0.84	Very high
2	0.84 to 0.25	High
3	0.25 to -0.25	Intermediate
4	-0.25 to -0.84	Low
5	<-0.84	Very low

Ganges and in Brahmaputra sediment areas of Bangladesh and the Godavari-Krishna delta.

As long as the data of the 11 characters (Table 3) are available, the method can be extrapolated to the soils whose characters remain within the range of variation of those of the original 410 samples. So far, some 200 such extrapolations have been made to evaluate the fertility of rice soils in the Mekong delta of Vietnam, in the Irrawaddy delta of Burma, and in Sarawak, Malaysia.

For the purpose of soil fertility classification, the whole range

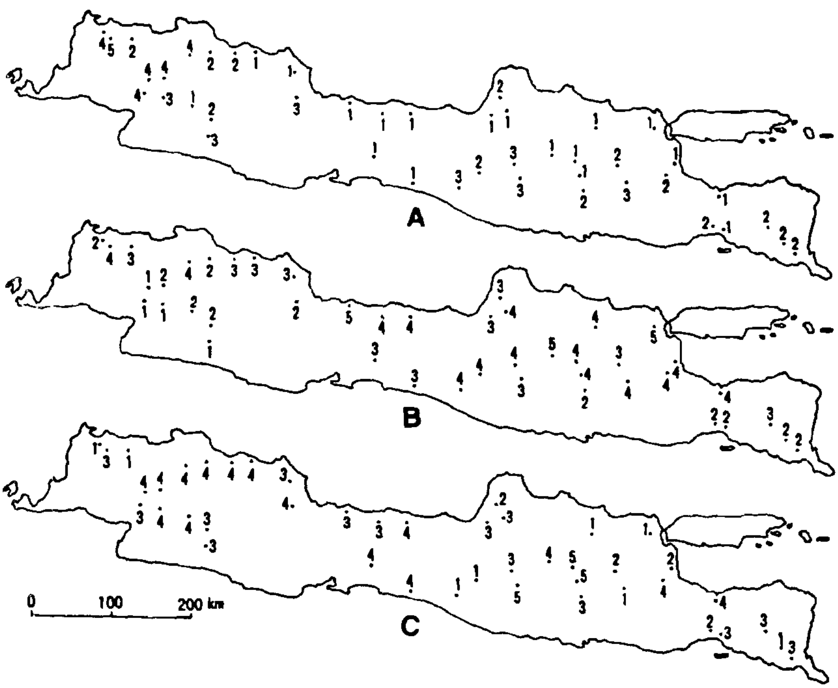

Fig. 1. Distribution of samples of soil from Java, Indonesia, in terms of A: inherent potentiality, B: organic matter and nitrogen status, and C: status for available phosphorus.

of computed scores was divided into classes, with arbitrary class limits of ± 0.25 and ± 0.84. The assumption underlying the selection of the limits is that if the distribution of the scores is normal, five classes of almost equal size should be formed (Table 7).

The distribution of the samples with different potentiality from one country or region can be mapped for each of the three fertility components with this five-grade classification (Fig. 1). In this way one can easily locate the areas with fertility problems.

The method is useful in giving an objective numeric rating of rice soil fertility and, further, in locating problem areas. Its drawback rests in the time- and labour-consuming processes of soil analysis. The computation itself is not too involved if a programmable calculator is available.

APPLICATION TO WEST AFRICAN SOILS

SAMPLES EXAMINED

Samples of wetland soils in some West African countries were collected from the areas either under use for rice cultivation or capable of supporting rice. Altogether, 71 soils were sampled from wetlands, i.e., valley bottoms, inland swamps, floodplains, and fault troughs: 51 in Nigeria, 9 in Liberia, 7 in Sierra Leone, and 4 in Cameroon. The general ecologic settings of the region have been explained in a report by Hekstra and Andriesse (1983).

Geologically these sample soils are derived either from Precambrian basement complex consisting mainly of granites, gneisses, and schists or from sedimentary rocks and deposits of various ages, Paleozoic through Quaternary.

Physiographically they occur either in coastal plains, interior plains, plateaus, or highlands. Those occurring in plateaus and highlands are almost exclusively derived from basement complex, while those occurring in the coastal plains are derived either from unconsolidated Quaternary deposits or from sedimentary rocks in the terraces. The soils taken from the interior plains are derived from both sedimentary rocks and basement complex.

Climatically the area of origin of the sample soils can be divided into four regions (Lawson 1981) depending on the length of positive water balance: 8 months or more in perhumid, 6–8 months in humid, 4–6 months in subhumid, and 2–4 months in semi-arid. Altogether, 17 sample soils were taken from the perhumid region, consisting of all 9 samples from Liberia and all 4 from Cameroon, 3 of 7 from Sierra Leone, and 1 from Nigeria; the remaining 4 samples from Sierra Leone and 20 samples from Nigeria made up the samples from the humid region, the total

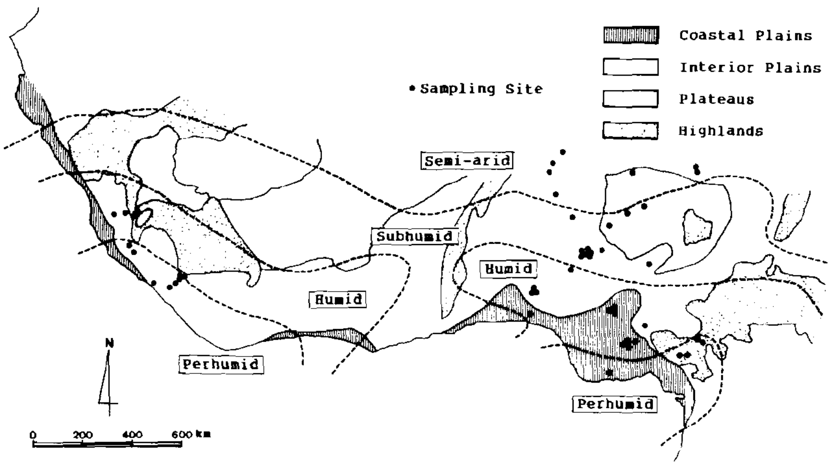

Fig. 2. Physiographic and climatic distribution of sites where soils were sampled in West Africa.

number being 24; and 23 samples from the subhumid region as well as 7 samples from the semi-arid region were represented by Nigerian soils.

The distribution of the samples (Fig. 2) is by no means representative of the wetland areas in the region, so that care must be taken in interpreting the results. In the following discussion, the climatic regions and countries are used as the frame of reference. However, the physiographic divisions are not referred to because, as far as soil fertility is concerned, they are less relevant than the local relief conditions.

FCC SYSTEM

There was no particular difficulty arising from applying FCC to the sample soils, although one complexity occurred in the use of the k modifier, which is used when the content of weatherable minerals is less than 10% of silt and sand fractions. Since we did not have the data of weatherable minerals, we had to adopt the second criterion, i.e., exchangeable K level of less than 0.2 meq/100 g or K saturation of less than 2% of the sum of bases if the latter is below 10 meq/100 g. Many of the samples had very low base status, often as low as 2 meq/100 g, so that even a very low exchangeable K, say 0.05 meq, did not satisfy the criterion of low K saturation. As it is presumed that most of the sample soils would not have more than 10% of weatherable minerals in silt and sand fractions, the k modifier should be applicable even though the criterion did not apply. We tentatively created a condition modifier k′ for the soils having less than 0.2 meq/100 g of exchangeable k, regardless of the level of the sum of bases (Table 8).

The pergleyic soils (g′) and strongly acidic soils (a) are more frequent in the perhumid and humid regions than elsewhere. Soils in the subhumid and semi-arid regions definitely have weaker acidity (h). But the nutrient status (k′) is low throughout. Thus the soils in the more humid regions have the modal soil characters of Lgaek′, while those in subhumid and semi-arid regions are characterized by Lgh(e)k′ and (L,C)ghk′d, respectively, where d means an ustic regime.

Country-wise, Nigerian soils are less acidic than those in the other countries, reflecting the major sample distribution in the less-humid regions. Cameroon soils are relatively high in CEC. Modal soil characters are L(g,g′)aek′ for Liberia, Lgaek′ for Sierra Leone, Lgak′ for Cameroon, and Lgh(e)k′ for Nigeria. For the total samples of West Africa the modal soil characters are expressed by Lg(a,h)ek′.

Except for a few soils in the drier regions, wetland soils in West Africa are low in nutrient reserves, low in nutrient retention

Table 8. Percentage frequency of appearance of the FCC symbols in four climatic regions and for four countries in West Africa.[a]

	Climatic region				Country			
	Perhumid	Humid	Subhumid	Semi-arid	Nigeria	Cameroon	Liberia	Sierra Leone
SAMPLES	17	24	23	7	51	4	9	7
TYPE								
S	12	33	17	14	27	0	11	0
L	71	58	74	43	59	75	78	86
C	18	9	9	43	14	25	11	14
SUBSTRATA TYPE								
S	12	42	13	0	6	0	11	14
L	82	50	74	86	92	75	89	86
C	6	9	13	14	2	25	0	0
MODIFIER								
g	59	83	100	100	90	100	44	86
g′	35	17	0	0	10	0	44	14
a	94	46	13	0	24	75	100	86
h	6	29	78	57	55	25	0	14
e	71	50	48	14	41	0	100	86
k′	94	86	78	57	78	75	100	100
d	0	0	0	71	10	0	0	0
b	0	4	0	14	4	0	0	0
n	6	0	0	0	2	0	0	0
MODAL SOIL	Lgaek′	Lgaek′	Lgh(e)k′	(L,C)ghk′d	Lgh(e)k′	Lgak′	L(g,g′)aek′	Lgaek′

[a]The figures are the frequency in percent of appearance of the type, substrata type, and condition among samples belonging to each of the areas.

capacity, and more or less acidic; in a word they are poor in soil fertility.

THE QUANTITATIVE METHOD

The scores of the three fertility components, i.e., inherent potentiality (IP), organic matter and nitrogen status (OM), and available phosphorus status (AP), were computed for each of the 71 wetland soil samples from West Africa (Table 3).

The mean IP score was lowest in the perhumid region, increasing toward drier regions. This means that the more intensive weathering and leaching conditions prevail in the humid regions.

The OM scores are generally high for the soils in humid to perhumid regions and low in the drier regions. But even in the semi-arid region there are soils with a positive OM score. As the samples were collected mostly from wetlands that are naturally inundated during the rainy season, they include many soils from swampy basins that may or may not dry up during the dry season. Those with a short period of desiccation are rich in organic matter even under quite dry climate. As a matter of fact two out of five soils with the FCC condition modifier d′ (ustic regime) had positive OM scores.

No definite trend appeared in the mean AP scores by climatic regions. These scores were slightly above zero for all the climatic regions but, for the semi-arid region, became negative when a sample with an extraordinarily high score (3.611) was excluded. There could be some human influence on the AP status through fertilizer application because phosphates are retained by the soil components.

As all the samples from Liberia were taken from the perhumid region, the mean IP score was low for the country. A high heterogeneity of Nigerian samples with respect to all three fertility components is a reflection of the wide variation of the climatic condition of the sample locations, as is the low mean score for OM. The overall means for the West African samples were IP = −1.171, OM = 0.699, and AP = 0.104.

This numerical evaluation confirms the poor fertility of wetland soils in West Africa. The inherent potentiality (conditioned by the nature and amount of clay and base status) is particularly low compared with Asian paddy soils. Although the rating for organic matter and nitrogen status is high, reflecting the climatic as well as local relief conditions, the potential will not be displayed unless the water regime is controlled and managed. Available phosphorus appears to be just comparable with that of Asian paddy soils; however, the Asian standard is much lower than that for a country like Japan. Thus, as far as West Africa is concerned, efforts must be devoted to raising the soil fertility.

Properties of some hydromorphic soils in West Africa

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Abstract *Samples of soils from 19 locations in Nigeria and 1 in Liberia were analyzed. The pH, exchangeable bases, contents of minerals and organic matter were determined, and the soils were classified according to fertility. The sites included inland valleys, coastal basins, and alluvial plains. The findings indicated that the soils are generally infertile and acidic. Also the cation exchange capacity is low.*

Given the vast area represented by hydromorphic soils in West Africa (see Andriesse elsewhere in this volume) and the site-specific variations, I attempted to characterize such soils from the humid rain forest and southern savanna of Nigeria. By comparing similarities and differences between Nigeria and Liberia, I drew some tentative conclusions about the water-holding capacity, fertility, and management of the soils in both countries.

MATERIALS AND METHODS

I took samples in 19 locations in Nigeria and 1 in Liberia (Okusami 1981) representing inland depressions, coastal areas, and alluvial plains. The samples were air-dried, ground, and sieved (2 mm mesh). I determined texture by the proportion of different sized particles using Bouyoucos hydrometer (Day 1953).

The pH was determined in deionized water (1:1) (Peech 1965). Exchangeable bases (i.e., Ca, Mg, Na, Mn, and K) were extracted with 1N NH_4OAc at pH 7 (Chapman 1965); Na and K were determined by flame photometer, and Ca, Mn, and Mg were analyzed on the atomic absorption spectrophotometer (Perkin-Elmer Model 403). Exchange acidity was according to the titration method.

Table 1. Fertility indicators from about the top 50 cm of some hydromorphic soils in Nigeria and one in Liberia.[a]

SOURCE/ sample	Depth (cm)	Texture	pH H_2O	CEC (meq/100 g)	Al (%)	Ca+Mg/ Ca+Mg+Al	Organic C (%)	Total N (%)	P (ppm)
COASTAL SEDIMENTS, NIGERIA									
020	0-12	Loam	4.6	4.0	14.5	0.84	1.52	0.153	2.7
	12-33	Loamy fine sand	4.7	3.0	48.7	0.45	0.32	0.056	1.8
030	0-12	Very fine sandy loam	5.4	5.3	0.0	1.00	0.95	0.113	12.0
	20-40	Loamy fine sand	4.7	1.7	13.7	0.85	0.47	0.050	5.1
040	0-7	Clay loam	5.7	14.2	0.0	1.00	2.43	0.316	57.9
	7-16	Clay	5.0	8.4	3.0	0.97	0.83	0.156	19.5
080	0-10	Fine sandy loam	3.6	5.2	26.4	0.62	2.78	0.319	9.6
	10-48	Sandy clay loam	3.9	3.3	82.8	0.05	0.54	0.066	1.2
INLAND DEPRESSIONS, NIGERIA									
050	0-30	Loamy fine sand	4.8	1.5	18.1	0.80	0.37	0.041	1.8
	30-37	Loamy fine sand	5.0	1.4	5.9	0.93	0.30	0.028	1.8
060	0-50	Loamy fine sand	5.1	1.4	0.0	1.00	0.50	0.038	1.2
100	0-25	Very fine sandy loam	4.6	2.9	21.7	0.75	0.87	0.094	2.1
	25-38	Very fine sandy loam	4.6	2.6	37.6	0.50	0.40	0.050	0.9
180	0-17	Sandy clay loam	5.1	10.5	ND	ND	1.32	0.090	2.5
	17-33	Sandy clay loam	5.2	8.1	ND	ND	0.44	0.040	0.5

INLAND DEPRESSION, LIBERIA									
190	0-15	Fine sandy loam	4.4	12.6	ND	ND	2.64	0.02	7.3
	15-30	Sand	4.5	3.4	ND	ND	0.47	0.04	2.3
ALLUVIAL PLAINS, NIGERIA									
090	0-36	Silt loam	5.0	7.9	1.1	0.90	1.24	0.156	9.6
110	0-10	Very fine sandy loam	4.6	2.1	19.0	0.70	0.64	0.056	11.7
	10-33	Very fine sandy loam	4.1	3.1	58.8	0.30	0.79	0.069	2.7
120	0-12	Silty clay	4.2	8.8	52.7	0.38	1.57	0.253	3.9
	12-56	Silty clay	5.2	8.7	54.1	0.42	0.75	0.109	1.2
130	0-11	Silt	4.5	2.9	41.5	0.51	0.95	0.102	4.5
	11-25	Silt loam	4.5	3.1	62.7	0.28	0.44	0.045	6.2
140	0-10	Silt loam	5.0	9.6	0.6	0.99	1.62	0.220	1.4
	10-27	Silty clay loam	4.6	8.9	11.8	0.87	0.75	0.134	0.6
150	0-20	Silt loam	4.7	2.3	22.3	0.73	0.68	0.063	2.4
	20-36	Silt loam	4.9	2.9	12.1	0.86	0.54	0.040	4.0
160	0-16	Silt loam	5.5	4.6	0.0	1.00	0.50	1.125	6.6
	16-24	Very fine sandy loam	5.1	2.4	18.0	0.80	0.37	0.100	1.5
	24-38	Loam	5.3	2.6	37.9	0.56	0.37	0.063	6.5
170	0-10	Loam	7.1	18.4	0.0	1.00	1.67	0.169	52.8
	10-17	Loam	7.1	14.0	0.0	1.00	0.99	0.103	11.7
	17-30	Clay loam	6.3	11.1	0.0	1.00	0.61	0.106	2.6
200	0-15	Fine sandy loam	4.2	4.6	ND	ND	0.36	0.050	4.1
	15-30	Fine sandy loam	4.2	3.8	ND	ND	0.13	0.030	7.4
	30-45	Loamy sand	4.6	2.5	ND	ND	0.01	0.020	5.1

[a]ND = not determined; data up to about 200 cm deep are available from author for most of the samples.

Exchange acidity ions were extracted with 1N KCl (McLean 1965). Effective cation exchange capacity was by summation of exchangeable bases and acidity. Easily reducible manganese (ERMn) was determined according to Adams' method (1965).

Organic carbon was determined by the Walkley-Black method on soil samples reduced to 0.5 mm particle size (Juo 1975). I determined total nitrogen by Bremner's method (1965), using particles 0.5 mm. Available P was by Bray-P_1 method (Bray and Kurtz 1945). Based on my findings, I used the fertility capability classification of Buol et al. (1975) to describe the soils.

RESULTS AND DISCUSSION

In Nigeria, the terrain has slopes of about 1-2%, but numerous undulations create great variability in soil types, depending on the seasonal fluctuations of the groundwater. Some areas are nearly flat. In Liberia, the inland swamps average about 2-5 ha, and the other sites suited to rice cultivation — Cretaceous sediments, floodplains, and terraces — are larger.

Suitability of the land for cultivation can partly be inferred from the morphologic characteristics of the soil — for example, the soil's ability to retain soil water or prevent rapid seepage during the life of the rice. I found that soils of the inland swamps and valleys are generally sandy loam to loamy sand (Table 1), so they have low water-holding capacity. Nevertheless, the swamps are found at low elevations, receiving high rainfall in Liberia (van Mourik 1979) and Sierra Leone (Odell et al. 1974), so they owe their hydromorphism to a perched water table. Within this category, the very fine soils can retain water for a significant portion of the growing season (pedons 020, 130, and 150 are typical examples in Table 1).

Most of the soils that undergo dry and wet periods each year have perched water tables during the rainy season. The bulk of hydromorphic soils on the Cretaceous sediments of southern Nigeria, for example, have this characteristic (Okusami 1981) as do the alluvial soils that span the savanna in West Africa. Nigeria is drier than Liberia (and Sierra Leone) (Bouvrie and Rydzewski 1977). Yet both regimes are suitable for two crops a year, of which at least one would be rice. Drainage would be needed for such a system in Liberia (Okusami 1981), whereas irrigation would be essential in Nigeria (Awotundun 1981). A few projects already incorporate these principles (Okusami et al. 1974; Ayotade 1979a).

Soil fertility is the key constraint in sustaining yields. The soils in the alluvial plains appear to be more fertile than their counterparts in the inland swamps or valleys. The latter are principally made up of intensely weathered soils from the adjacent

Table 2. Fertility capability classification and designations according to *Soil Taxonomy* for some hydromorphic soils in Nigeria.

Pedon	Classification according to *Soil Taxonomy*	Type[a]	Modifier[a]								
			g	d	e	a	h	i	x	v	k
020	Aeric Tropaquept, loamy, mixed	S	+	+	+		+				+
030	Plinthic Tropaquept, fine loam, mixed	L	+	+	+		+				+
040	Oxic Aeric Tropaquept, very fine clay, kaolinitic	C	+				+				
050	Aquic Ustifluvent, sandy, siliceous	S	+	+	+						+
060	Aquic Ustipsamment, sandy, siliceous	S	+	+	+		+				+
080	Aquic Oxic Tropudult, fine loamy, kaolinitic	L	+	+		?	+				+
090	Aquic Dystropept, fine silty, kaolinitic	L	+	+			?				
100	Typic Tropaquult, coarse silty, kaolinitic	L	+	+	+		+				+
110	Aquic Ustifluvent, coarse silty, kaolinitic	L	+	+	+		+				+
120	Aquic Ustifluvent, fine clay, kaolinitic	C	+	+			+				+
130	Oxic Plinthaquult, loamy skeletal, kaolinite	L	+	+	+	?	+				+
140	Oxic Plinthaquult, loamy skeletal, kaolinite	L	+	+			+	?			
150	Aeric Tropaquept, fine silty, kaolinite	L	+	+	+		+				+
160	Oxic Plinthaquult, coarse silty, kaolinitic	L	+	+	+		+				+
170	Umbric Aeric Tropaqualf, fine clayey mixed	L									
180	Ustorthent	L				ND	+				
190	Tropaquent	L				ND	ND				
200	Tropaquent	L				ND	ND				

[a]S = sand; L = loamy; C = clayey; g = gley; d = dry environment; e = low CEC; a = aluminum toxicity; h = acidic; i = high fixation of phosphorus by iron; x = x-ray amorphous; v = Vertisol; k = potassium deficient; ? = borderline; ND = not determined; + = modifier describes sample of soil.

An inland valley in the northern guinea savanna of Nigeria where farmers cultivate vegetables such as peppers and potatoes in the dry season. The soils in this area are not as infertile as those in the humid tropics.

uplands and are likely to predominate in the inland valleys and swamps of Liberia as well (pedon 190, Table 1). The soils in the alluvial plains are "younger" than those of the inland swamps or valleys.

Because of the shallow roots of rice plants, the quality of the topsoil strongly influences production. The topsoil in the samples I took was generally acidic, within the range associated with aluminum toxicity. However, as the acid in waterlogged soils would be diluted, the ratio of exchangeable Ca + Mg to Ca + Mg + Al alone may be a reliable measure of the threat of aluminum toxicity, as outlined by Odell et al. 1974.

With few exceptions in the pedons studied, the cation exchange capacity was very low and indicates that prolonged cropping without fertilizer is not feasible. The coastal sediments have greater potential to support continuous cropping than do the inland swamps and valley bottoms since the former are mixed clays — kaolinite, smectite, and hydrous mica.

Organic matter is generally low in these soils, with an average value less than 1%, most of which is found in the uppermost horizon or two, i.e., shallower than about 25 cm. One reason for the low values is that the harvested residues are usually removed from the field (Okusami 1981). Total nitrogen and available P are closely related to organic matter, indicating that the reserves of these elements are mostly from the organic matter.

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Easily reducible Mn is also generally low in the soils, although there were a few exceptions in the samples I collected.

The subsoils exhibited somewhat higher fertility status since they contain more clay minerals than does the topsoil. Soluble iron was excessive in many of the soils from the inland swamps and valleys as well as in soils of the alluvial plains that are adjacent to highly weathered upland soils. Ayotade (1979b) made similar observations about iron concentrations in the soil in his comments on the bronzing and failure of rice on such soils.

Within the fertility capability classification scheme (for the A horizons or plow layer, whichever is shallower) the soils are generally loamy with few sandy and clayey profiles. Potassium deficiency (k modifier) is common, as is the low CEC (e) and the lack of dominant amorphous (x) materials (Table 2). When air-dried, the soils are acidic (h), although not concurrently with Al toxicity (a).

DISCUSSION SUMMARY

Which types of wetland can be developed immediately for rice production?

Small inland valleys and river floodplains in traditional rice-producing areas should receive first priority. For planning purposes, one must have good information on the land, soil, and hydrologic characteristics of the area.

Is there any relationship between soil moisture and soil fertility?

In general, soils with high fertility are more easily reduced when flooded than are infertile soils; however, water regime has no direct relationship with soil fertility. Iron toxicity of rice is attributed to both soil enrichment and soil impoverishment.

WATER MANAGEMENT

Water flow, balance, and control in rice cultivation

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Abstract *During the past 20 years in Japan, researchers have been investigating water movement in paddy fields to develop theory and practices that ensure efficient use of water in producing high yields of rice. They have found that the water primarily moves downward at a rate determined by the presence and distribution of macropores in the soil as well as by the thickness, air exchange capacity, and hydraulic conductivities of the top two layers of soil. The rate of percolation of the water can be measured somewhat indirectly by the change in depth of surface water at times when there is no rainfall or flow of surface water into or out of the system. By slowing the rate of percolation through the field, one can maximize the time that inputs such as fertilizer are available to plants and minimize water requirements. Percolation rates of 15–35 mm/day are associated with maximum yields in Japan. To reconcile the goals of using inputs efficiently and maintaining a healthy environment for the plants, farmers usually attempt to reduce to zero the rate of percolation and then drain the field mid season. They knead the soil, patch "leaks" with bentonite, etc. and install pipes, bamboo, etc. to act as drains. Water movement in paddy fields differs considerably from that in upland fields. Consequently, most of the concepts and the measures to control water movement in paddy have been developed separately from those in upland fields and have their own peculiarities.*

CHARACTERISTICS OF WATER FLOW IN PADDY FIELDS

Generally, the soil of a paddy field during ponding is regarded as saturated or nearly saturated with water. Air bubbles are trapped in

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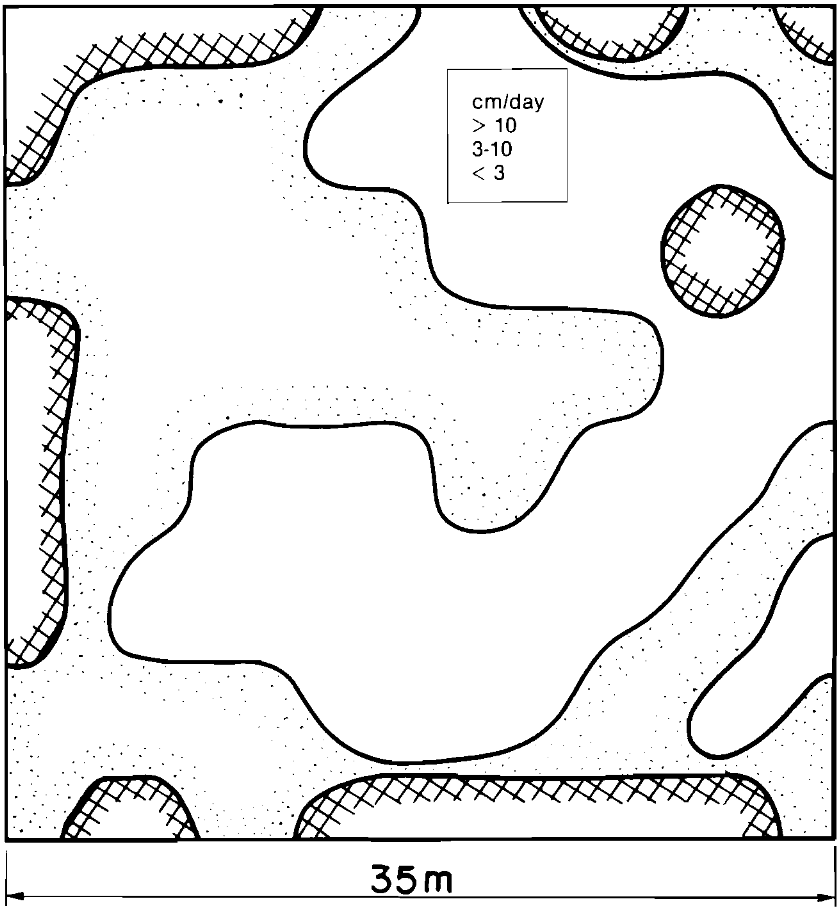

Fig. 1. Uneven distribution of percolation rates measured in 64 places, 5 m apart, by a quick seepage meter. The values ranged from 0.2 cm/day to 35.5 cm/day (Yamazaki et al. 1962).

the plowed layer under natural conditions. The saturation gives the flow some characteristics:

- It is predominantly percolation, with the water moving mainly through the macropores; therefore, the percolation rate (or hydraulic conductivity) is not uniform across the field.
- The direction of water movement is fundamentally downward so the soil profile is invested with special chemical and physical properties.
- In stratified conditions two types of flow exist, depending on the thickness and hydraulic conductivities of the upper and lower layers of soil and the depth of the water table.

SPATIAL VARIABILITY

As macropores in the soil are formed by soil fauna, plant roots, cracks, fissures, and so on, they are distributed unevenly. The lack of uniformity is reflected in the rate at which water percolates in a paddy field (Fig. 1).

Ishikawa et al. (1963) investigated the percolation rates in an area of about 50 paddy fields and found a minimum of 0.4 cm/day and a maximum of 38 cm/day. These differences probably reflect the spatial variability of fissures and cracks. The variation decreases gradually year by year after land reclamation but, in the meantime, makes it difficult to obtain the average percolation rate in a paddy field.

In clayey paddy fields, many macropores formed by rice roots can be observed in layers below the plowed layer. Using roentgenography, Tokunaga et al. (1985) identified pores as small as 50 μm. The shapes of the pores were similar to those of rice roots, with vertical pores having diameters 60-90 μm. The result is anisotropism in permeability of the soil (Table 1). The values for the ratio of vertical to horizontal hydraulic conductivity were near 1.0 in a plowed layer 5-10 cm deep, in Iwatsuki (Masujima 1966) and in an 80 cm deep sublayer in Yahaba (Tokunaga et al. 1985). The anisotropism appears to have been averaged by plowing in the former case, whereas, in the latter case, no roots had permeated the layer.

DOWNWARD PERCOLATION

In stratified soil conditions, a less-permeable soil layer often lies over a permeable layer, and the groundwater exists below the boundary plane of the two layers. Even when the soil is uniform at reclamation, this condition is present later, as a plow-sole layer is formed.

Two patterns of water flow occur under such conditions (Fig. 2). One is found in both closed and open systems, and the other is found only in an open system. In a closed system, the air in the soil is

Table 1. Anisotropism in permeability of soils from clayey paddy fields at three sites in Japan.

SITE/ Reference	Depth (cm)	Hydraulic conductivity (cm/s) Vertical (A)	Horizontal (B)	B/A
KAWASATO/	20-25	1.9×10^{-4}	1.4×10^{-5}	0.07
Masujima 1966	35-40	2.9×10^{-4}	2.1×10^{-5}	0.07
IWATSUKI/	5-10	2.4×10^{-3}	2.1×10^{-3}	0.88
Masujima 1966	15-20	4.0×10^{-5}	1.9×10^{-6}	0.05
	35-40	6.0×10^{-3}	7.0×10^{-7}	<0.01
YAHABA/	15	1.5×10^{-4}	3.0×10^{-7}	<0.01
Tokunaga et al.	35	2.8×10^{-4}	5.7×10^{-6}	0.02
1985	80	2.0×10^{-7}	1.9×10^{-7}	0.95

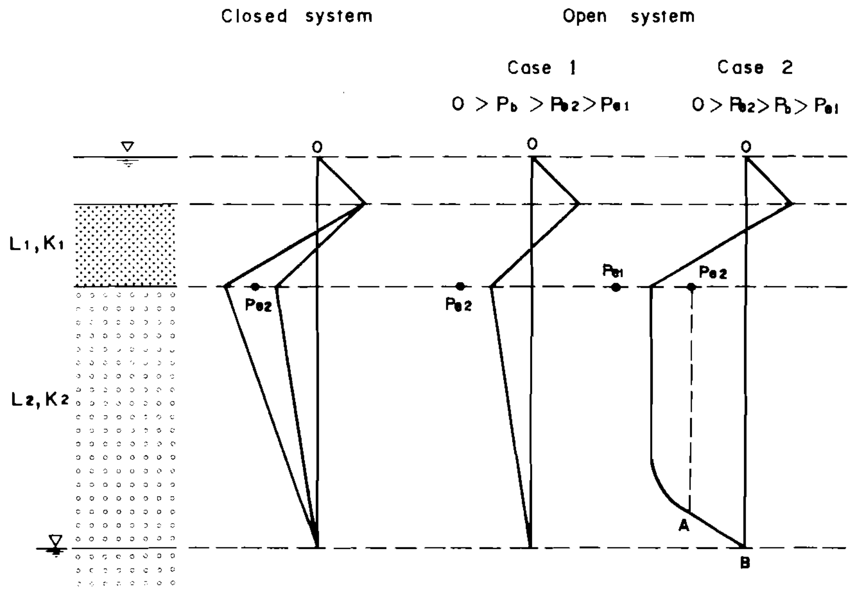

Fig. 2. Patterns of water pressure in paddy fields where L is the soil layer, K is the hydraulic conductivity, P_b is the pressure at the boundary plane, and P_e is the pressure exerted by air exchange from the atmosphere.

trapped, whereas in an open system the air can be exchanged with air in the atmosphere (Yamazaki 1948). Generally, water in upland soil flows in an open system. In a closed system, if the water flow is steady, the pressure at the boundary plane, P_b, is given by (equation 1) (Tabuchi 1969):

$$P_b = [L_2(K_1L_1 + K_1h - K_2)]/(K_2L_1 + K_1L_2) \tag{1}$$

where, K_1 and K_2 are the hydraulic conductivities of the upper and lower soil layers, h is the depth of water, L_1 is the thickness of the upper layer, and L_2 is the thickness of the lower layer above the groundwater table. P_b becomes negative when (equation 2):

$$K_2 > K_1\ (h/L_1 + 1) \tag{2}$$

If the air bubbles are few in a closed system, the soil in both upper and lower layers is assumed to be saturated, and K_1 and K_2 are equal to the saturated conductivities. Therefore, in a closed system, soil water suction is not a unique function of soil moisture.

As is well known, air enters the soil when the water pressure in the soil decreases below the air-entry pressure, P_e, for example in paddy fields that are on a platform adjacent to an upland field or a deep canal (Yamazaki 1948; Takagi 1960).

In an open system, if the pressure at the boundary plane, P_b, is higher than the air-entry pressure at both layers, P_{e1} and P_{e2} ($P_{e2} > P_{e1}$ because of the stratified soil), the distribution of water pressure is the same as in a closed system. However, when P_b is smaller than P_{e2} and larger than P_{e1}, much of the lower layer (except the part between A and B in Fig. 2) functions as an open system. Then, a range, in which the hydraulic gradient, J, is unity, can be found in the upper part of the lower layer.

WATER BALANCE IN PADDY FIELDS

The water balance equation for a given time is (equation 3):

$$RA + Q_1 + G_1 = Q_2 + G_2 + A(ET) + \Delta S \tag{3}$$

where, R is rainfall, A is the area of the field, Q_1 and Q_2 are the amounts of surface inflow and outflow water, respectively, G_1 and G_2 are the amounts of subsurface inflow and outflow water, respectively, ET is the evapotranspiration, and ΔS is the change in

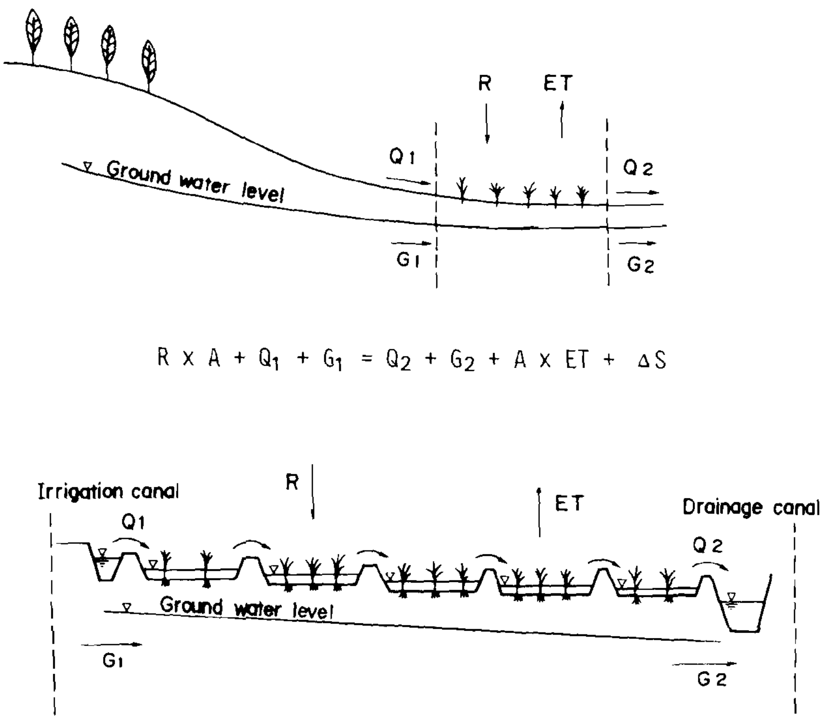

Fig. 3. Schematic representations of rainfall (R), surface water inflow (Q_1) and outflow (Q_2), groundwater inflow (G_1) and outflow (G_2), and evapotranspiration (ET). The area of the field falls between the dotted lines.

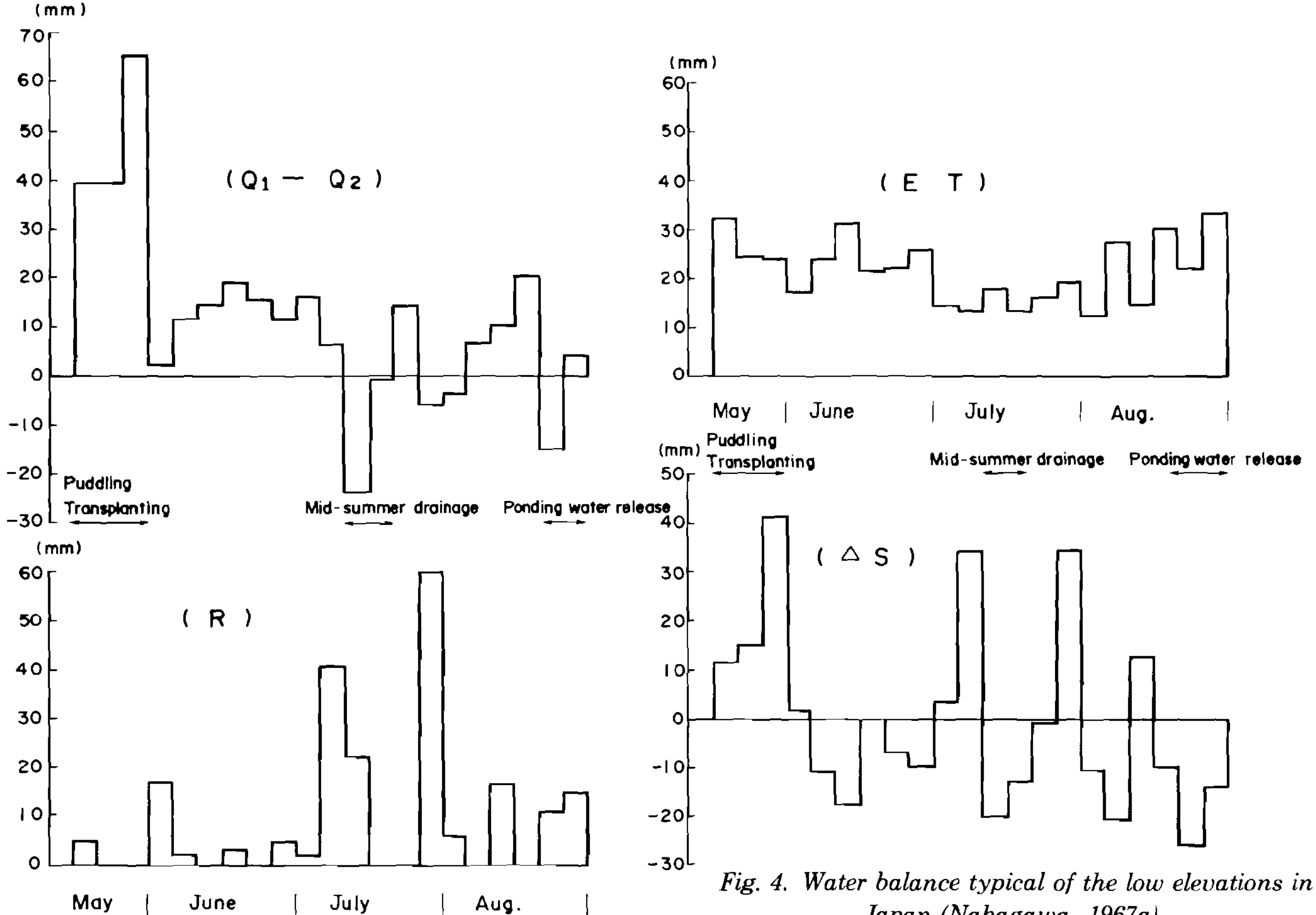

Fig. 4. Water balance typical of the low elevations in Japan (Nakagawa 1967a).

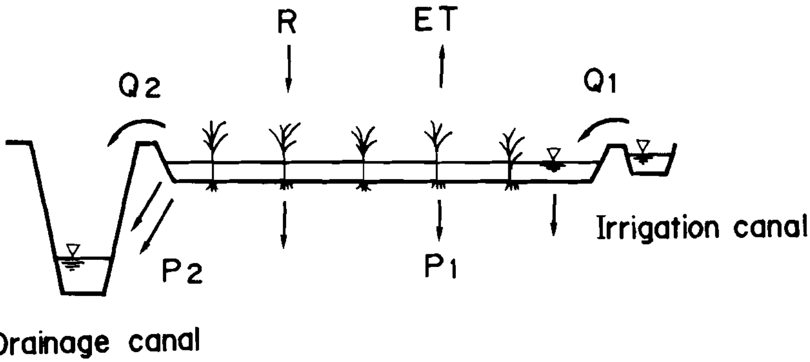

Fig. 5. Schematic representation of rainfall (R), evapotranspiration (ET), water percolated downward (P_1) and through the levee (P_2), as well as surface water inflow (Q_1) and outflow (Q_2).

the amount of water stored in and on the soil (Fig. 3). If water depth is kept constant, ΔS can be considered to be negligible. At low elevations, G_1 and G_2 are also negligible because the impermeable soil layer, on which groundwater is stored, is usually flat. The resulting water balance is quite typical in Japan (Fig. 4), but puddling and midsummer drainage, which are performed throughout most of the country, affect the water balance. The amount of water needed for puddling ranges from 100 mm to 150 mm (Nakagawa 1967a). The equation (4) for water balance in a paddy field is:

$$Q_1 + RA = Q_2 + P_1 + P_2 + (ET)A + \Delta S \qquad (4)$$

where, P_1 and P_2 are the amounts of water percolated downward and through the levee, respectively (Fig. 5). As the percolation rate in a paddy field is uneven and the task of measuring P_1 and P_2 directly would be practically impossible, another measurement called "water requirement in depth" has been used in Japan. It equals the sum of P_1, P_2, and ET: a scale or hook gauge is used to measure the decrease in depth of surface water in the paddy field under conditions without rainfall, surface inflow or outflow. Usually, the value is expressed in mm/day (Fig. 6).

Although the word "requirement" implies that water must be added to the system, "water requirement in depth" is seldom equivalent to water consumption in an area of paddy fields in Japan. Often, water that percolates from one plot is used in irrigation for other plots in the same area (Table 2). For example, the water flowing into a drainage canal is pumped to other plots or is channeled elsewhere by dams. Or surface water on a plot at one elevation is supplied to the surface water of an adjoining plot at a lower elevation

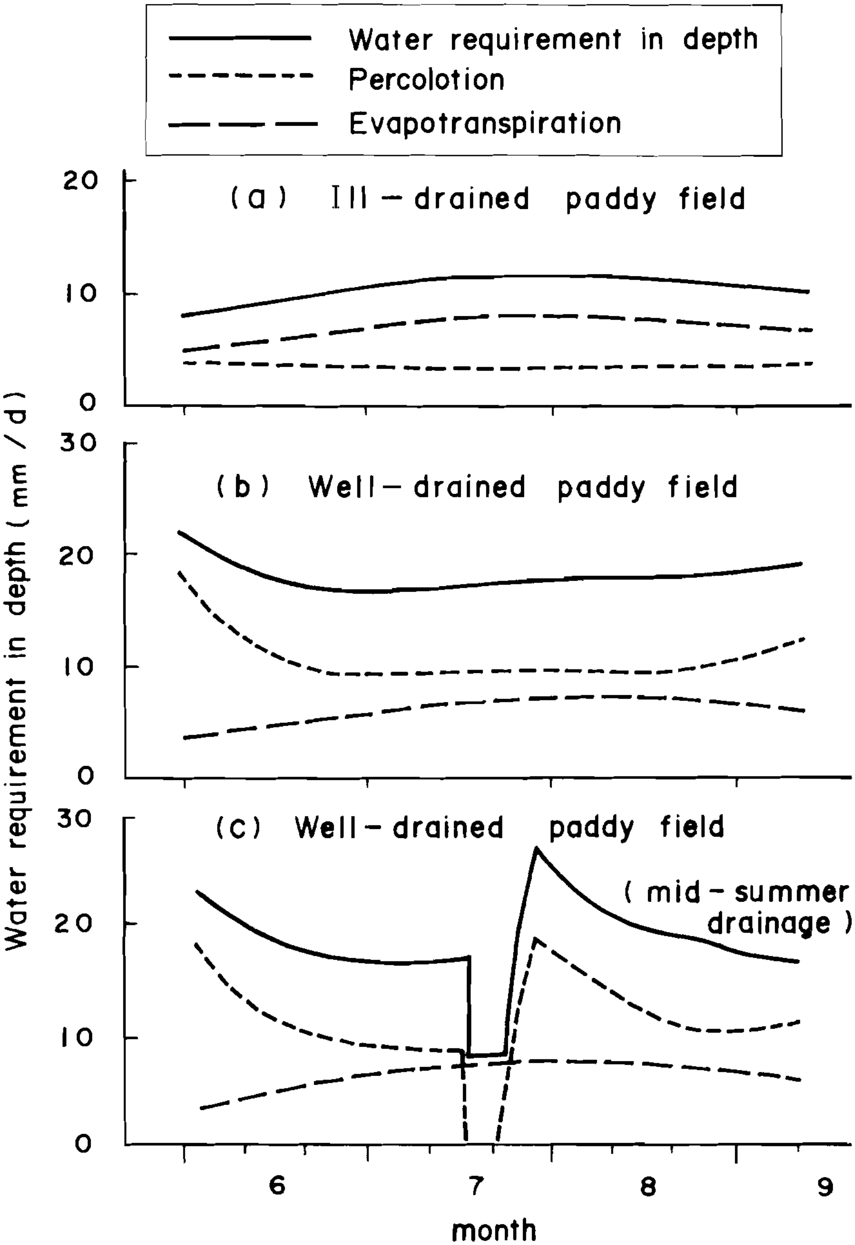

Fig. 6. Examples of water requirements in depth from land preparation to harvest in paddy fields in Japan (Nakagawa 1967a).

Table 2. Water consumption by paddy fields at five sites in Japan.

Site	Terrain gradient (%)	Area (ha)	Water flow (mm/d)			
			In	Out	Consumption	Requirement
Mu river, Hokkaido	0.10	1080	52	42	10	32
Hazama river, Miyagi	0.05	1600	22	14	8	14
Naka river, Saitama	0.1-0.01	44960	15	8	7	17
Ryoso Togane, Chiba	0.10	100	14	5	9	10
Komino, Saitama	0.10	300	7	3	4	13

through levee percolation. At times, water consumption in an area of low-lying land is nearly equal to the evapotranspiration in the area. More often, however, 50–70% of the amount of water taken in from a river for irrigation flows into drainage canals and is used again to irrigate paddy fields downstream in Japan (Nakagawa 1978) (Fig. 7).

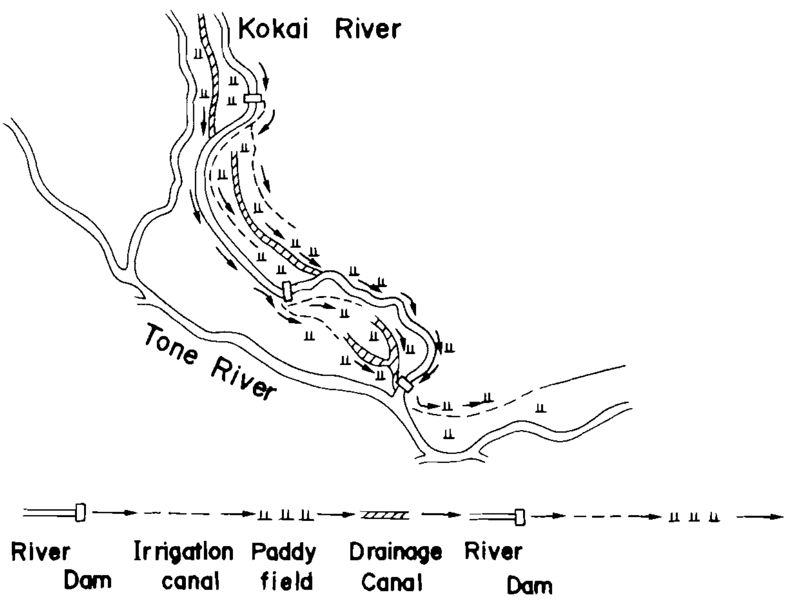

Fig. 7. Schematic representation of water reuse in Japan (Sudo 1978).

OPTIMAL PERCOLATION RATE

The magnitude of percolation in a paddy field determines the amounts of air supplied to the soil, the harmful materials removed, and the nutrients lost. In addition, it can greatly influence the soil temperature. The higher the rate of percolation, the greater the amounts of water and fertilizer required and, in cool conditions, the greater the risk of cold damage to the crop. The negative effects, however, are at least partially offset by the increased air supply and the removal of harmful materials. The key is to find an optimal percolation rate.

The relationship between percolation rate and rice growth has been reported by several researchers in Japan. According to Shiroshita et al. (1962), plants in ill-drained fields (with a percolation rate of near 0) absorb little K_2O, N, or P_2O_5 after forming panicles and nil at flowering, whereas plants in well-drained (20–39 mm/day) fields continue to absorb the nutrients until maturity (Fig. 8). The percentage of ripened grains of rice in the ill-drained field examined by Shiroshita et al. was considerably lower than that in the well-drained field, and after the panicle-forming stage the weight of dry matter per hill in the well-drained field became larger than that in the ill-drained field.

Kawada and Ishihara (1961a) studied the effects of percolation rate on root growth. They established two experimental plots — one with no percolation and one with moderate percolation. Their results indicated that the physiologic activity of primary roots in the latter plot was much higher than that in the former. Other researchers obtained similar results (Ueda and Oyama 1958; Yamada and Ohta 1961; Shiroshita et al. 1962). Kawada and Ishihara (1961b) also researched the effects of formic acid, acetic acid, and butyric acid in an attempt to simulate the effects of decomposing organic matter in the soil. They found that all the acids, even at the low concentrations observed in paddy fields, hinder the growth of rice roots (Table 3). Later, Ishihara (1967) concluded that the acids checked the growth of rice in areas where percolation was slow. Midsummer drainage, performed generally in Japan, is a reasonable way to eliminate the acids. Whether the conclusion by Ishihara is valid in climates different from Japan is not clear and would have to be studied.

Isozaki (1957) investigated the relationship between yield of rice and water requirement in depth in the paddy fields in Gifu prefecture, in the middle of Japan, and found that yields were maximum in paddy fields whose water requirements in depth were 20-30 mm/day. This value corresponds to a percolation rate of 15-25 mm/day, which Isozaki named the "optimum percolation rate". Later, many researchers investigated the values for optimal percolation in other areas in Japan. According to their results,

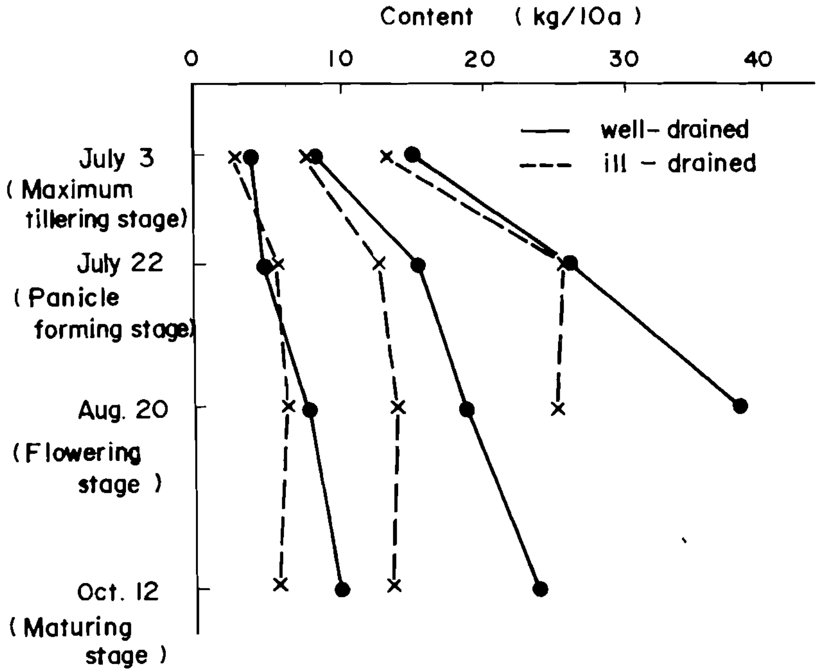

Fig. 8. Nutrients absorbed by rice at four stages of growth in well-drained and ill-drained paddy fields (Shiroshita et al. 1962).

optimal percolation rates in Japan range from 15 to 35 mm/day. However, the percolation rate exerts great influence only when expected yields are more than 6 t/ha (Honya 1966).

CONTROL OF WATER MOVEMENT

In Japan, soil puddling, soil dressing, subsoil compaction and levee coating have been adopted as methods to slow percolation, whereas

Table 3. Effects of formic, acetic, and butyric acids on growth of primary roots of rice.

	Concen-tration (mmol)	Root growth during 4 days (cm)	Total length of root hairs (μm)
Control	0.0	5.8	199
Formic acid	2.5	2.0	51
Acetic acid	2.5	5.3	18
Butyric acid	0.3	4.6	23

drainage through open ditches and pipes is used to promote percolation.

SLOW THE RATE OF PERCOLATION

The hydraulic conductivity of a soil is reduced remarkably by kneading. Negishi et al. (1972) reported that hydraulic conductivities for soils other than sand could all be reduced to less than 10^{-5} cm/s if the air-dried particles (<2 mm) were saturated with water and kneaded well. Fujioka and Nagahori (1963) also found the percolation rate of a soil containing more than 25% clay could be reduced to less than 25 mm/day simply by puddling. In studies of a silty loam, Sasaki (1977) found that one puddling during the crop rotation reduced hydraulic conductivity to one-fifth and three puddlings reduced it to one-tenth. Water requirement in depth decreased correspondingly, whereas, in a paddy field without puddling, the percolation rate (and hence the water requirement) increased rapidly each year (Fig. 9).

Puddling destroys the structure of the soil, prevents weed growth, and facilitates transplanting. However, it may be an unsuitable practice in areas where an upland crop or a vegetable is grown after rice.

Even with puddling, some paddy fields, especially those on sandy soils, have unacceptably high rates of percolation. Applying a dressing of clayey soil or bentonite is one way to staunch a leaking paddy field. At a dressing of 7 t/ha, bentonite reduces the rate by 50-80% (Yamazaki 1971). The bentonite is broadcast in the field and mixed (by puddling) with the plowed layer of soil. The greater the uniformity is, the higher the efficiency of the dressing. Bentonite

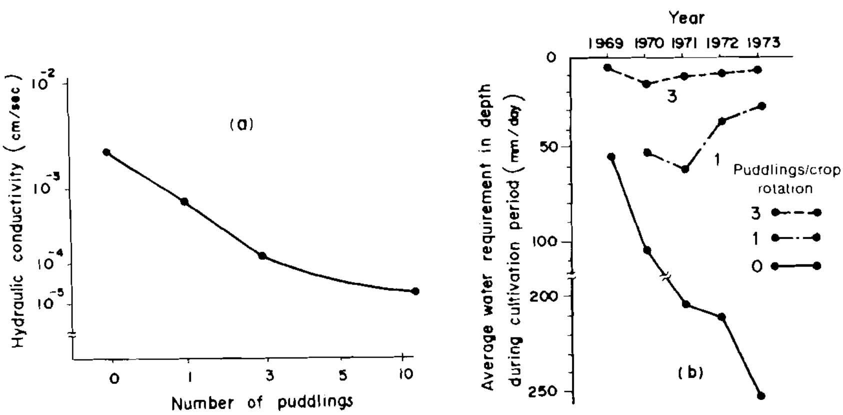

Fig. 9. Relationship between puddling and (a) hydraulic conductivity and (b) water requirement in depth (Sasaki 1977).

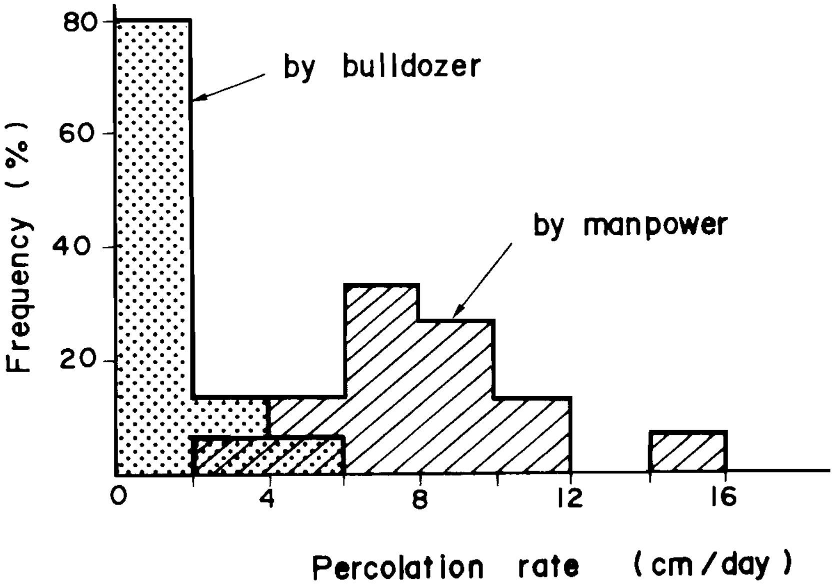

Fig. 10. Frequency distribution of percolation rates in paddy fields constructed by hand and by a bulldozer (Yamazaki et al. 1961b).

swells, and Kita et al. (1964) found that it promotes dispersion of the soil particles. Moreover, soil dressing improves other physical and chemical properties such as water-holding capacity and cation exchange capacity of the soil.

Compacting the subsoil also slows percolation, but the surface layer (20 cm) of soil must be removed before soil compaction by human or mechanical means. According to results obtained in the 1920s, labourers compacting a paddy field reduced the water requirement in depth by 67% compared with 80% by a tractor equipped with a roller. In general, percolation rates in a paddy field constructed by bulldozer are lower and more uniform than those in a field constructed by labourers under the same soil conditions (Fig. 10) (Yamazaki et al. 1961b). However there are soils that cannot be compacted effectively even by bulldozer: volcanic ash is one. The microcapillary pore structure of such soils is so firm that it cannot be broken by the bulldozer. The structure has to be destroyed by deep rotary tiller before compaction. Ishikawa et al. (1964) showed that the water requirement in depth could be reduced from several hundred millimetres per day to fewer than 20 mm/day by crushing before compaction.

For paddy fields with a drainage canal on a slope in an alluvial fan, percolation rates greater than 10 cm/day may exist in the vicinity of the levee. Yamazaki (1971) found that the range of rates

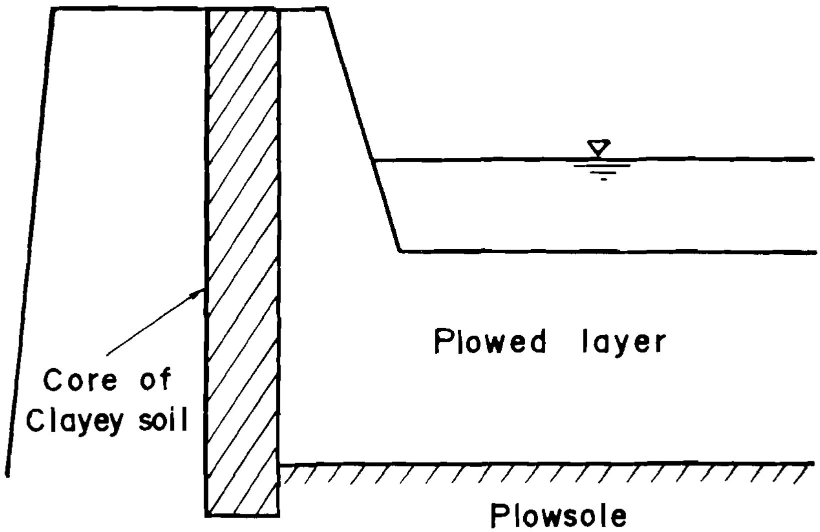

Fig. 11. Core of clayey soil to prevent percolation losses through a levee.

for levee percolation was generally much wider than that for downward percolation in a field and the values of percolation per unit length (m) were sometimes 10 times the downward percolation per unit area (m^2). This means that, if the paddy field is 100 m × 30 m, the water loss through levee percolation is nearly equal to the loss through downward percolation.

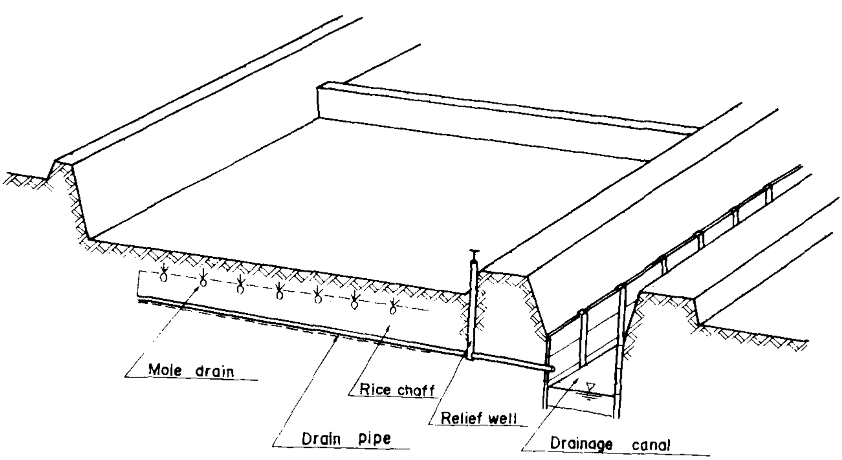

Fig. 12. Drainage system common in Japan.

To prevent levee percolation, rice growers apply a coating of clayey soil that has been kneaded well with water. A core of clayey soil is often used for levees with very high percolation rates (Fig. 11).

DRAINAGE

Drainage of paddy fields (increasing the percolation rates in ill-drained paddy fields) has two major purposes:

- To counteract reducing conditions that hinder rice growth; and
- To increase the bearing capacity of the field for farm mechanization.

Canals are the most common method of drainage but — if they prove insufficient — mole drains, simple drains (using wood, bamboo, or stones), or pipes are introduced. In valley bottoms, where

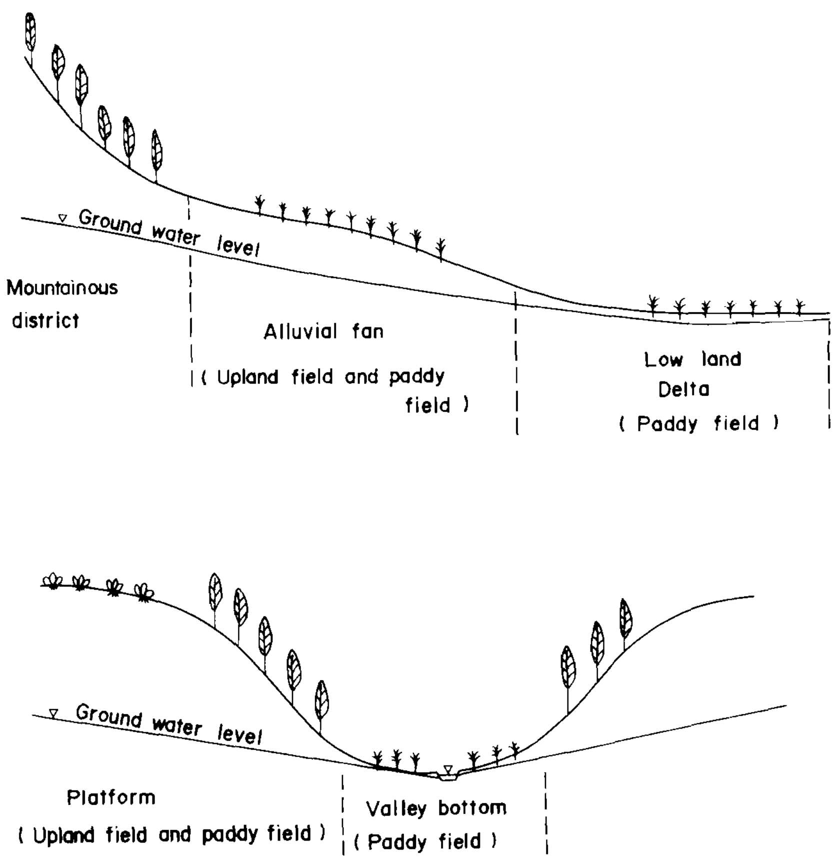

Fig. 13. Classification of paddy fields according to their positions on the landscape in Japan.

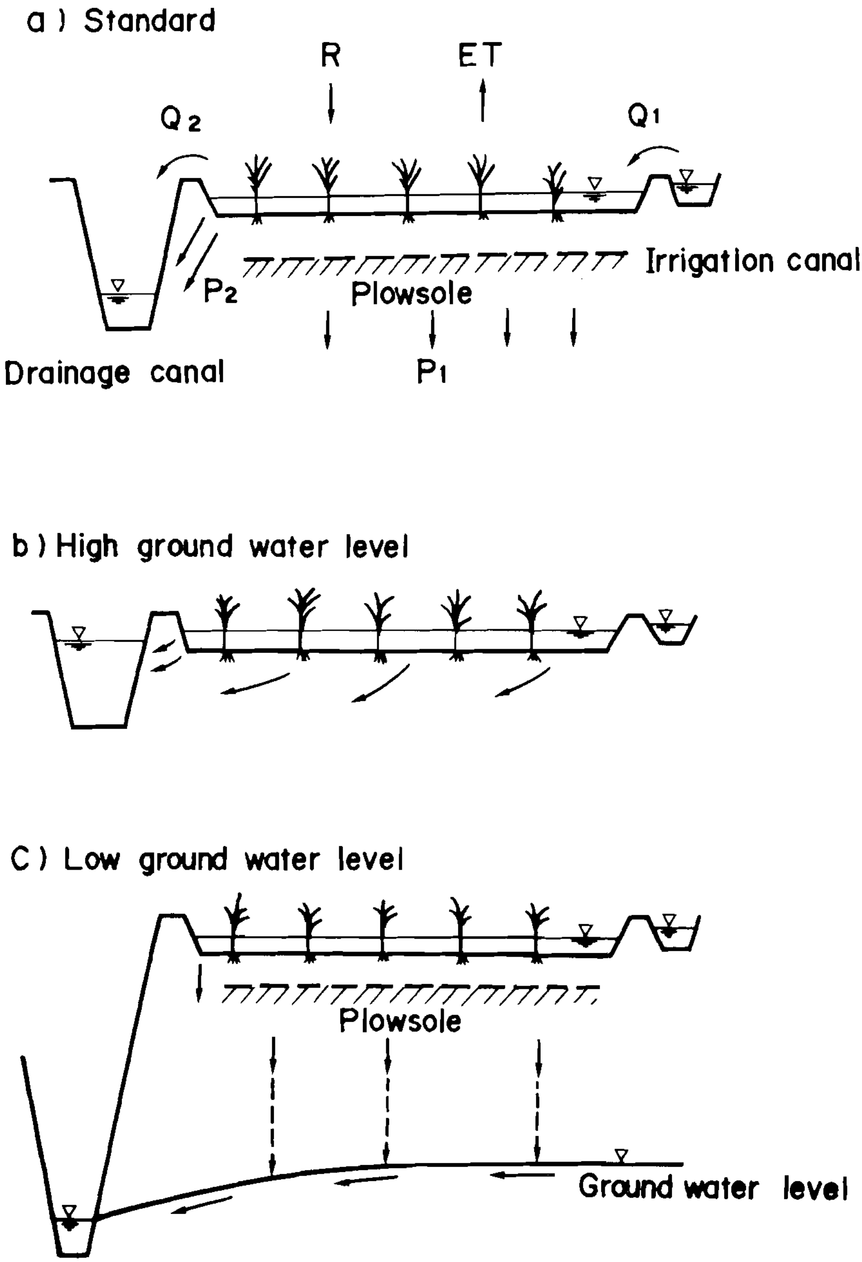

Fig. 14. Classification of paddy fields according to the groundwater levels in Japan.

Roentgenogram of the clayey soil reveals pores produced by the roots of rice. The technique to study the porosity of the soil was developed by Tokunaga (1985).

horizontal or upward underflows are often observed, deep canals or drain pipes placed at the boundary of the paddy fields and the hill slope are effective means of intercepting the flows.

In clayey paddy fields in Japan, pipes spaced 10 m apart and 70-90 cm deep have proved effective (Fig. 12) (Negishi et al. 1972). After the installation of drain pipes, the trenches are backfilled with rice chaff up to the plowed layer. Mole drains are constructed across the rice chaff. At the outlet of each drain pipe is a relief well that is closed during irrigation.

As the surface of a paddy field is generally uneven, some ponded water remains after drainage. This residual water is usually 30-50 mm deep and can be removed only by subsurface drainage or evaporation (Tabuchi et al. 1966). If evaporation is minimal at

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harvest, the residual water must be drained quickly so the soil surface can dry before harvesting by combine. Shrinkage cracks develop in the subsoil and function as water paths if they are interconnected and have outlets at the rice chaff backfill. Consequently, the subsurface drainage of clayey paddy fields improves year by year.

CONCLUSIONS

These methods of water control have been developed in response to problems in paddy fields in Japan (Fig. 13 and 14) but may prove useful elsewhere. The information that has been gained during the past 20 years allows one to manipulate conditions in paddy fields to effect optimal water use.

A model to assess proposed procedures for water control: application and results for two small inland valleys

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Abstract *A model for calculating water balance was applied to two areas — Bida, Nigeria; and Makeni, Sierra Leone — that are the focus of an IITA project on wetland use. The purpose was to determine whether the inland valleys in the two areas were suitable for use in paddy cultivation. Data on rainfall and natural drainage were used for calculation of the changes in groundwater and for estimations of the amount of time the inland valleys would have enough soil moisture to support paddy rice. The calculations were also used to estimate whether the time could be usefully extended by the construction of contour bunds to store water on the fields. The findings indicated that, in Bida, bunds (with a spillway height of 0.15 m) would extend the period of positive water balance by about 20 days in wet years but not at all in dry years, whereas, in Makeni, they would extend the time by about 50 days in both wet and dry years. The implications are that in the small valleys (fadamas) near Bida, cultivation of lowland rice is risky even with bunds and in Makeni the bunds would extend the season long enough to permit a second crop of rice.*

We conducted a study of the agrohydrologic conditions in Bida, Nigeria, and Makeni, Sierra Leone — the two areas that are the focus of a research project by IITA investigating wetland utilization. Our aim was to determine how long (during the cropping season) paddy conditions were present in the inland valleys in the areas and whether the time could be usefully extended by construction of contour bunds with a spillway height of 0.15 m.

The design of an agricultural water-management system requires a good understanding of the occurrence, nature, and movement of water. This means careful study of the total rainfall and its distribution as well as the availability and changes in groundwater.

One can assume that at the beginning of the rainy season, there is a deficit of soil moisture. Therefore, to produce paddy conditions, the rainfall in the valleys must first replenish the groundwater so that it reaches the surface. The excess rain becomes surface runoff unless stored on the fields by bunds.

In the uplands, excess precipitation (precipitation over potential evaporation) infiltrates and contributes to moisture stored in the soil, draining fully (but not steadily) into the valleys until the retention capacity is exceeded. It then percolates deep and is not available for upland crops. If evaporation exceeds precipitation, soil moisture diminishes until it is fully depleted.

THE AREAS

The Nigerian area studied is in the Nupe-Sandstone formation, consisting of sandstones, silt, and clay. The scenery is rather uniform, a series of plains with ironstone capped hills (mesas). The land has a rather low drainage density (0.17 km/km^2) (Table 1) of a dendritic pattern. Weathering has been substantial, and there are no rock outcrops. Ironstone is found only in the form of eroded remnants. The topography is flat to undulating, with predominant slopes of 1-2% (seldom more than 8%), and the average valley slope is 0.35%. The area drains into the Gbako river. Located in the guinea savanna, the area has moderate rainfall with a monomodal to

Table 1. Area, slope, and drainage of sites in Bida, Nigeria, and Makeni, Sierra Leone.

	Bida, Nigeria		Makeni, Sierra Leone	
	Kunko	Echin Woye	Matam	Rogbom
Area (ha)	800	1300	160	250
Upland	755	1250	100	180
Fringe	30	30	30	35
Valley	15	20	30	35
Valley				
Length (m)	1500	1500	2000	2000
Width (m)	20-120	10-70	30-150	20-150
Gradient (%)	1.0-2.0	0.5-1.0	0.3-0.7	0.3-0.7
Drainage density	0.17	0.17	1	1

pseudomodal pattern. Average annual rainfall is 1200 mm, and the rainy season lasts about 4 months. Mean monthly temperature fluctuates from 26°C to 31°C.

The area in Sierra Leone is in the interior plains of the Precambrian basement complex. It consists of gently undulating plains of moderately shallow sandy-clay loams with ironstone gravel, intricately dissected, with small granite outcrops. The drainage density (1.0 km/km^2) is much higher than that found in the Nigerian site. Typical valley slopes are gentle, and the valleys broaden into featureless depressions (Table 1). Slopes of the transition zone between the uplands and valleys can be steep. Rock outcrops in the valley are frequent and indicate a shallow profile on bedrock. The two experimental sites in the area drain into the Mabole and Pampona rivers respectively. Located in a high rainfall zone, with a monomodal pattern, the area receives an average 3100 mm annually, the rainy season lasting about 8 months. Mean monthly temperature fluctuates from 26°C to 29°C.

STUDY METHODS

From rainfall data, we defined the start of the rainy season as the day that rainfall for a 10-day period exceeded 40 mm in Bida and 60 mm in Makeni. The rainfall before April was excluded because it was erratic and certainly not part of the rainy season. From rainfall data for 10-day periods we calculated probabilities for nonexceedance at 20%, 50%, and 80%. Although one should be aware that a 10-day period with 20% chance of nonexceedance could be followed by a period with 80% chance, the comparison with potential evaporation gives an idea of the duration and the reliability of the cropping season.

To describe the pattern of rainfall, we analyzed the maximal rainfall for 1, 2, 3, 5, and 10 consecutive days, assuming a Gumbel distribution for extreme values.

To calculate the groundwater flow, we employed the method of de Zeeuw and Hellinga (1960) who developed a formula for nonsteady discharge:

$$Q_t = Q_{t-1}e^{-\S t} + R_t\,(1 - e^{-\S t})$$

where § = reaction factor (1/day) that allows for the difference in drainage between uplands and lowlands, t = time interval (days), Q = discharge (mm/day), and R = recharge (percolation) (mm/day).

For the water-balance calculations, we assumed a starting point in the beginning of January, although the water table in the valley in some years (for example, when the rainy season of the previous year extends to December) would not be at its lowest level at this time.

Even so, this assumption does not cause large errors, as the beginning of the year remains dry for at least 90 days. Hence, the initial conditions — i.e., a deficit in soil moisture — are always valid at the beginning of the rainy season.

However, the calculations for the nonsteady groundwater flow are only indicative. One reason is that the conditions during a 10-day period are assumed to be constant during the interval. Another reason is that the reaction factor is a rough estimate.

For the Makeni area, a reaction factor of 0.038 was assumed on the basis of observed data. For the Bida area, no data were available so a reaction factor of 0.006 was estimated from values for a sandy area in the Netherlands (de Zeeuw 1966). The two areas were assumed to be hydrogeologically comparable.

No surface runoff from the upland area was taken into account. The permeability and infiltration characteristics were high, and surface runoff would occur only when rainfall intensity exceeded a certain threshold. The available data for 10-day periods do not allow the threshold to be taken into account.

In the model, potential evaporation data were used. Although these are fairly realistic for paddy conditions, they overestimate the evapotranspiration of the uplands in the beginning of the season and hence underestimate deep percolation. Later in the season, with a fully developed crop, the reverse may be true. On the other hand, all rainfall was considered effective, and clearly this is not the case. This assumption is supposed to compensate for the evapotranspiration error.

The retention capacity was based on an available moisture capacity of 15% (sandy loam) and a rooting depth of 0.80 m. ($0.8 \times 0.15 = 0.12 = 120$ mm). The moisture deficit in the valley bottom was based on an air capacity of 22% at field capacity (sandy loam) and an assumed groundwater depth at the end of the dry season of 0.5 m. Half of the moisture capacity between field capacity and wilting point needs to be replenished before the profile is fully saturated and inundation starts [$0.5(0.22 + 0.075) = 0.1475 = 147.5$ mm: say 150 mm].

We calculated the water balance for four conditions:

- Uplands;
- Lowlands without groundwater flow, with bunds;
- Lowlands with groundwater contribution, without bunds; and
- Lowlands with groundwater contribution, with bunds.

For the uplands as well as for the lowlands, the total number of 10-day periods with an uninterrupted positive water balance was counted. For the uplands, the water balance was considered positive when soil moisture exceeded the wilting point. For the lowland paddy crop, the water balance was considered positive only when water was ponded in the fields without interruption.

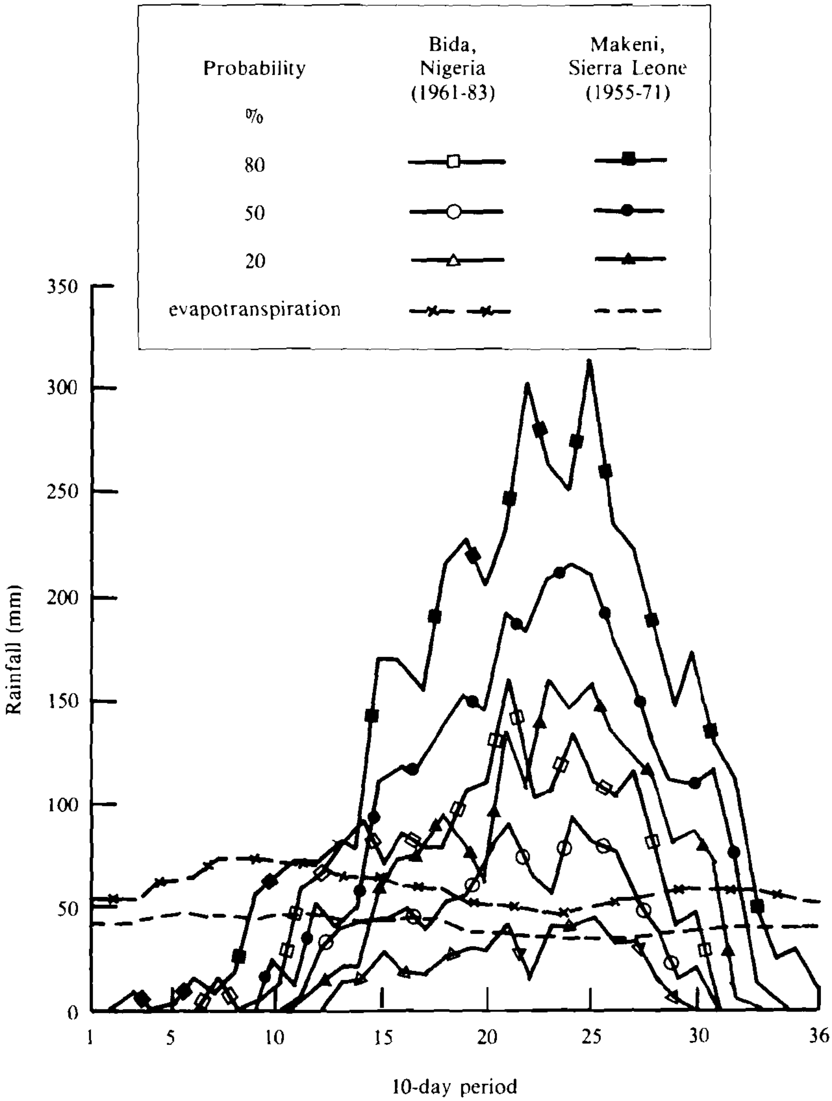

Fig. 1. Probability of nonexceedance in Bida, Nigeria, and Makeni, Sierra Leone.

RESULTS

The distribution of rainfall varies much more in the drier zone in Nigeria than in the high rainfall area in Sierra Leone (Fig. 1, Table

Table 2. Yearly rainfall totals for Bida and Makeni calculated from a review of more than 15 years' records.

	Bida	Makeni
Years of records	1961–83	1955–71
Rainfall totals (mm)		
Mean	1200	3170
Maximum	1640	3679
Minimum	842	2866
Standard deviation	205	225
Coefficient of variation	0.171	0.071

2), as does the duration of the rainy season. We found that the start of the rainy season for both areas is about day 115 and the average duration is 130 and 245 days for Bida and Makeni respectively (Table 3). Average rainfall exceeds potential evaporation during only 8 × 10-day periods in Bida compared with 20 × 10-day periods in Makeni (Fig. 2). Maximal rainfall in the Bida area occurs normally as single storms: the 1-day storm is only marginally surpassed as the period extends. In Makeni, rainstorms are normally part of a rainy period (Table 4).

The model showed the importance of the contribution by groundwater in the valleys near Bida: it contributed little during dry years, but during 7 out of every 10 years, it increased by 80 days the

Table 3. Variability in the start and duration of the rainy seasons in Bida and Makeni.

Frequency (years)	Starts before day		Duration (days)	
	Bida	Makeni	Bida	Makeni
1 out of 5	99	98	150	275
1 out of 2	117	115	130	245
4 out of 5	165	144	105	215

Table 4. Maximal rainfall (mm) for 1, 2, 3, 5, and 10 consecutive day(s) in 1 out of every 2, 5, and 10 years.

Consecutive days of rain	Total rainfall (mm) in 1 of 2, 5, 10 years					
	Bida			Makeni		
	2	5	10	2	5	10
1	80	106	123	131	182	216
2	96	126	146	177	237	276
3	104	132	151	211	293	347
5	124	154	173	266	356	416
10	173	218	248	366	443	494

Table 5. Numbers of 10-day periods when the water balance is likely to be positive in upland and paddy fields (with and without bunds and contributions from groundwater) in Bida and Makeni at six levels of probability (%).

	10-day periods when water balance is likely to be positive at confidence levels (%) of:					
SITE/setup	95	90	80	70	60	50
BIDA						
Upland	7.0	9.0	10.5	12.0	12.5	13
Paddy						
Bunds, no groundwater	0.0	0.9	4.0	5.5	6.5	8
Groundwater no bunds	0.0	0.9	6.0	14.0	18.5	20
Bunds, groundwater	0.0	0.9	9.0	15.0	19.0	21
MAKENI						
Upland	19.0	20.0	21.5	22.5	23.5	25
Paddy						
Bunds, no groundwater	18.5	19.5	20.5	21.5	22.5	23
Groundwater, no bunds	19.5	20.5	21.5	22.5	23.0	24
Bunds, groundwater	22.5	23.5	26.0	27.8	27.0	28

time that the water balance is positive, and in 6 out of 10 years it increased the time by 110 days (Table 5).

For Bida, in the 5 years from 1979 through 1983, 2 years (1979, 1983) were extremely dry, and no water could be held on the field. According to the calculations, the contribution of groundwater during these years was nil: there was no deep percolation. This finding is in agreement with local experience: in interviews, farmers said that yields of rainfed lowland rice during that period were almost nil.

During the same 5 years, 1982 showed a positive water balance for 6 and 9 × 10-day periods without and with groundwater contribution respectively. However, this interval would be too short to assure a good paddy crop.

According to the model, bunds, and the water stored by them, would contribute marginally, although the result may partly be explained by the time interval used (10-day periods). During dry years, when groundwater flow is absent, rainfall is not sufficient to maintain a layer of water on the fields so the bunds contribute nil. During years with good rainfall, the bunds increase the period in

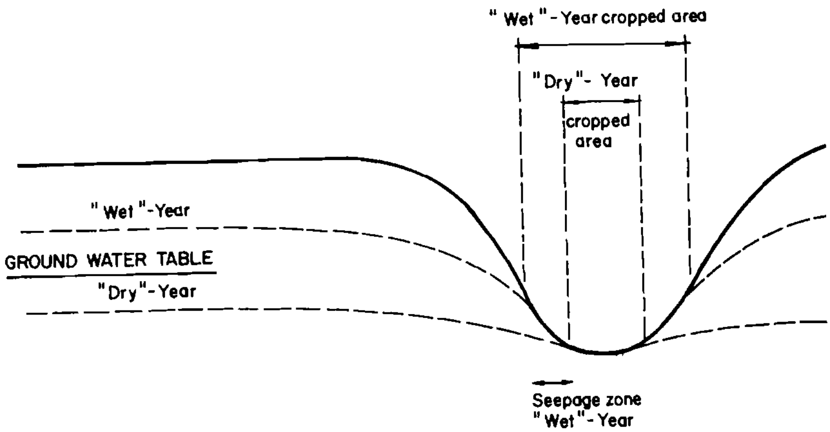

Fig. 2. Seepage zones and cropped valley bottom in wet and dry years, Bida, Nigeria.

which water balance is positive by about 20 days but this variation of the reaction factor leads to no substantial differences.

The water-balance calculations indicate that production of lowland paddy rice in the Bida area is risky and that hydromorphic rainfed rice is probably a more acceptable crop.

During wet years, the groundwater flow is considerable, and farmers tap the seepage zones for rice cultivation (Fig. 2). The slow response of the groundwater reservoir and the steady flow of groundwater after the end of the rainy season enable farmers to concentrate on rice cultivation in the valley only when the rainy season has been good.

For Makeni, the influence of groundwater is far less pronounced: during dry years the groundwater increases the time that the water balance is positive by about a single 10-day period to 210 days. However bunds increase this time by more than 5 × 10-day periods. The total number of days with a positive water balance is about 260 — a value suggesting that the conditions are suitable for two crops of paddy a year.

The model does not take the concave shape of the valley into account so does not reflect the effects of bunds on distribution of water.

The model should be further tested but its use in our study has proved promising — a means to predetermine the feasibility of improvements in water management.

IMPROVEMENT OF RICE VARIETIES

Strategies and approaches to wetland rice improvement

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Abstract *In subsaharan Africa, conventional approaches to breeding rice are not likely to produce the types of improved varieties that are required. The conventional emphasis on yield potential is inappropriate because high-yielding varieties already exist. What is needed is a focus on developing varieties that can be direct seeded and are resistant or tolerant to the stresses found in rice-growing environments in Africa. Agronomic research should be toward improved methods of seed preparation and of soil preparation as seedbeds and on efficient weed control for direct-seeding conditions. The traditions of African farmers, their inclinations, and their problems (weeds, diseases) as well as their implements and resources determine the utility of new varieties. The entire range of high-yielding varieties available elsewhere needs to be tested, with none being disregarded simply because it is not resistant or tolerant to stresses in Asia or Latin America. Rice yellow mottle virus, which is indigenous to Africa, had not even been described before susceptible varieties from Asia were introduced into Africa. Breeders should abandon their quest for varieties that are widely adaptable and begin to select varieties that produce well in particular environments and are acceptable to local consumers. Innovative approaches are needed. For example, stress (nutrient, cold, and drought) could be used as an aid in selecting for tolerance and resistance to several unrelated pathogens (Buddenhagen 1981b). Blast, along with other foliar fungal problems, and panicle disease are closely related to environment, and the relationship could be exploited by breeders.*

Every field, every farm is its own reality. Good farmers in long-established, stable farming regions know the idiosyncracies of their fields. However, imbalances that have the potential to upset productivity radically occur when new pests, pathogens, crops, or

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varieties are introduced or when inputs (fertilizer, herbicide, pesticide, water) previously considered normal are reduced.

In the wetlands of Africa, the effort to increase total productivity is pushing old land uses, old stable systems, toward radical change. This publication is about change — major modifications of agriculturally underutilized wetland ecosystems.

The conference on which this publication was based was held to help catalyze the changes in land and water management that will influence practically every aspect of the physical and biological environment.

In Asia, where the major work on modern breeding of rice has been carried out, the environmental modifications of wild wetlands into rice paddies occurred over millennia, with adaptation and selection of local landraces by ancient farmers being largely completed toward homeostasis long before modern science. Modern high-yielding varieties (HYVs), with their improved capability to use nitrogen, greatly increased production, but they also destabilized old, balanced ecosystems, and, after the initial development, most work has gone toward attempting to bring back stability genetically, by addition of genes to improve resistance. At first the focus was genes for resistance to disease, then to pests, then lately for tolerance to various soil imbalances. The genetic approach has not solved all the problems, so considerable effort in Asia has also been applied to developing rice pesticides and measures for "integrated pest management" (IPM).

I think the major question is whether improvements in Africa must go the way of Asia in terms of ecosystem changes and destabilization or whether strategies exist that could shift the present ecoysystems from low to high productivity without major imbalances, such as pest and pathogen explosions and negative soil-varietal interactions.

My belief is that given sufficient understanding of historical changes and evolution in biology and in agricultural development, breeders can focus on "balanced ecosystem adaptation" that will lead to increased productivity without causing instability, new epidemics, or requirements for greater pesticide use. The changes will, however, require greater water control and increased use of fertilizers and herbicides — these cannot be escaped.

ECOSYSTEMS IN RELATION TO CROP IMPROVEMENT

Crop improvement is really the attempt at matching plant genetic combinations with environmental characteristics to maximize production of a desired product. There are three major elements:

variable genetic material, variable environments, and people's desires as to product.

The traditional breeding program concentrates on manipulating the variable genetic material — on making crosses, on looking at segregating generations in experimental plots, and on measuring yields of derived fixed lines in trials on experiment stations. Environmental variability is reduced to a minimum, and often plots are sprayed to reduce insect pest variables and to allow expression of "yield potential". Breeders naturally concentrate on breeding material; they have been trained that way. Their training is usually heavily weighted toward breeding, genetics, and statistics.

There is a tendency to overemphasize raw yield potential in experiment station trials and to underemphasize the variability of the environment and the true need for an acceptable appearance, taste, and yield of the refined product.

To match an environment with the most adapted and productive variety or population, one must have a good knowledge of the environment. Hence, the ecosystem and agroecosystem have to be characterized and understood (Buddenhagen 1977, 1983a; Moormann and van Breemen 1978; Moormann and Veldkamp 1978), especially in tropical Africa where crop and ecosystem are in a state of rapid flux and where the agroecosystems are many and diverse. Thus, there is considerable potential for innovative research to match environments with the rice crop's vast genetic variability.

I have written extensively on this theme over the last 10 years (Buddenhagen 1973, 1977, 1978, 1983a,b,c; Buddenhagen and de Ponti 1983) and have presented these ideas at several conferences. At first, the ideas fell mostly on deaf ears; the vogue was "broad adaptability". The pattern already existed of accepting the need to use large quantities of insecticides and to replace collapsed varieties with new varieties. I was even called to task for using the word "ecosystems".

But gradually there has been a change and there is now much more concern for specific environmental adaptation and for varietal stability. There is more realization that rice-growing situations are diverse and that to breed for them one needs more knowledge about their physical and biological parameters. There is more realization that a variety's failure in adaptation cannot be economically rectified in poor countries by costly pesticides. There is more realization that breeding for adaptation to local ecosystems is a worthwhile endeavour and that stability is as important as "yield potential".

I welcome this trend because it enables local breeders and other local scientists in country programs to have better, more productive careers wherein they themselves can do local creative research rather than just test materials brought in from far away.

THE RICE AND WHEAT "GREEN REVOLUTION"

One of the major reasons for the great success of rice and wheat breeding in the last 25 years was the strong element of environmental control behind the strategy and for the breeding target. For wheat it was a narrowing of the target with promotion of irrigation and good water control, and narrowing the soil idiosyncracies by addition of fertilizers. This was a conscious decision and effort promulgated most vigorously by Dr Norman Borlaug. Rice differed in that good water control already existed in the millions of hectares of rice paddies, just waiting for a short, nitrogen-responsive variety. For both crops, the physical environmental targets were narrow and thus similar across wide regions. Broad adaptation worked partly because it wasn't really needed. The regions were broad but the physical ecosystems were circumscribed and quite narrow.

Problems arose with the biological environment — pests and pathogens were different in different places, thus upsetting "broad adaptability". But, more importantly, where the crops were grown in environments without good water control, the improved varieties were much less successful. In fact, breeding has met with little success in the tropics except in response to imbalances caused by new-encounter (Buddenhagen 1977) diseases and pests or where hybrids could be exploited. For such crops, yield potential is already high, but the potential is expressible only in good environments where stresses are either naturally low or easily and economically reduced (Buddenhagen 1983b). The tropics has few such situations, outside originally dry regions now irrigable or in rice paddies. Flooding soil is the great equalizer.

The development of wetlands in Africa is not just to utilize underutilized land, but to take advantage of the great equalizer of flooding soils, which automatically confers much stability and productivity to rice cultivation. Diverse ecosystems become narrowed. The water controls many diseases, and the breeding targets are clear. Improved varieties for irrigated conditions have already been developed, as have suitable agronomic practices. It is a matter of adoption and economics, and these are matters for education and policies on import restriction and trade.

RICE ECOSYSTEMS IN TROPICAL AFRICA

The key strategy for rice improvement in tropical Africa should be, in my view, to develop breeding targets around realistic rice ecosystems and geographic divisions.

Although rice improvement for wetlands narrows breeding targets somewhat, an analysis of the wetlands in Africa reveals that diverse ecosystems are involved (Buddenhagen 1978; Moormann and Veldkamp 1978). In earlier work at IITA we divided rice culture into four main types and eight subtypes (Table 1). A more logical classification is that of Moormann and van Breemen (1978) of pluvial, phreatic, fluvial, and irrigated rice.

The major drawback of these classifications is that they transect climatic divisions. And climate, especially the amount of rain and the length and continuity of the humid period, provides the major influence on the biologic stresses — the diseases and insects — that affect the rice crop. Temperature also influences these stresses, and cool nights favour blast disease in mid-altitude areas or in northern and southern latitudes.

Thus, although one may classify rice culture, it is the position of the field geographically in relation to the climatic zones and their evolving biota, and altitudinally, that determines the targets for resistance breeding, including that of cold as well as for diseases and pests. Even photosynthesis rates and yield potential will be influenced by how far into the forest zone or into the desert zone the rice culture is to be.

Additionally, climate (plus parental rock material and time) is the major determinant of soil characteristics (IRRI 1985), which can be either suitable or inappropriate for rice culture. Thus, salinity or alkalinity may be problems in desert areas, toxic levels of iron and manganese or insufficient cations in wet forest zones, etc. Varietal performance will be influenced by such factors, and breeding approaches need to be adjusted accordingly.

Thus, the rice agroecosystem is a particular type of rice culture that is based on the seasonal relations between soil and water and is set in a particular location whose original setting is the determinant of the parent preagricultural ecosystem. The challenge for the

Table 1. Classification of rice culture in Africa.

Rice	Subtype
Upland Hydromorphic	Dryland
Irrigated	
Inland swamp	Toxic Nontoxic-toxic
Flooded	Riverine shallow Riverine deep Boliland (dambos) Mangrove

breeder and for the germ plasm is to integrate the diverse interactions.

WETLAND DEVELOPMENT IN RELATION TO RICE IMPROVEMENT

How much will a push on wetland development change the existing hectarage and location of rice culture in Africa? Breeding programs should be influenced by the answer to this question, which at the moment can only be a guess.

Rice productivity potential increases as wild wetlands are developed toward greater and greater water control, with assured water sources and regulated water depth and movement. Thus, one could envision a trend toward irrigation in hydromorphic as well as swamp cultivation depending on location and water reliability. It is hard to see boliland changing much. It is hard to see mangrove swamps changing much. The big potential, however, seems to me to be in changing riverine and relatively flat but now dry areas in river basins into irrigated fields. Thus, growers will probably continue to need medium-statured varieties suitable for hydromorphic cultivation and flooded situations in different climatic zones. They will also need high-yielding dwarfs for irrigated fields with good water control. The latter should be targeted separately for savanna, forest, and mid-altitude zones. Different resistances and levels of resistance will be required for each.

Breeders should develop new varieties in anticipation of improvements in wetland development and management. They should work with development projects so that they can adjust their targets quickly as new problems are encountered and so seed supplies of new better varieties can be expanded quickly.

AGRONOMIC PRACTICES AND RICE IMPROVEMENT IN AFRICA

The management of wetlands depends on both macro changes (dams, canals, drainage, etc.) and micro changes in land preparation, weed control, etc. I believe that to make rice production work on a big scale in Africa it should deviate from the Asian transplanting approach. Not only is the African not used to transplanting, he or she has avoided wetlands over the centuries for good reasons — the extra hard work and waterborne diseases, for example.

I consider that a major research program should combine agronomic and breeding efforts to come up with varieties and practices that will work together for direct seeding of rice regardless of the type of rice culture. The research should have subdivided targets of the different types and locations of wetland culture. Breeding efforts should be toward materials that germinate and grow through some level of warm water in an irregular seedbed. Agronomic research should be toward improved methods of seed preparation and of soil preparation as seedbeds and on efficient weed control for direct-seeding conditions. Some years ago I voiced this thinking at IITA and started some work, but the too-ready acceptance of Asian rice-growing methods led to the abandonment of such African-targeted objectives. I submit that rice researchers in Africa should attack this problem vigorously with a focus on the traditions of African farmers, their inclinations, and their problems (weeds, diseases), as well as their implements and resources. I have seen many inland valley swamps in Liberia and Sierra Leone, earlier in transplanted rice culture, abandoned once the outside push was relaxed. This should be a lesson.

An interesting comparison is rice development in Latin America which, like Africa, had no Asian traditions. Rice development there did not go the direction of transplanted rice and it remains almost entirely a direct-seeded crop, regardless of the type of rice culture.

In California, all rice-breeding plots are sown directly with a simple device that enables three people to sow 4000-row plots/day. With this device and good herbicides, a large improvement program is feasible with low labour costs. I recommend its practicality for Africa.

Some effort might go usefully into selecting for characters like early canopy cover to help suppress weeds.

QUALITY CHARACTERISTICS

One may think that rice quality in Africa, wherein rice has not been a traditional staple except in a few areas, is less important than in Asia. Additionally, local rice in local markets, with its poor milling and mixed seed types, suggests that quality, as perceived in, for instance, Thailand, would not be an important target. But I think this is not so for several reasons. First, as rice consumption has increased in the burgeoning cities in recent years, well-milled, long-grain rice, even of quick-cooking "Uncle Ben's" from the USA, has been imported, and competition from imports of high-quality, low-cost rice can be expected to intensify in the future. Second, the earlier-introduced rices in the Sahel were high-quality, long-grain rices from the Vietnam region. Third, although generally poorly milled, many of the old landraces in West Africa have very good taste and cooking quality even though they are not long grain. And, fourth, African traders are at least as sophisticated as any.

All of these points indicate a need to have quality as part of a holistic breeding strategy. Probably two targets are realistic: a long-grain "Uncle Ben's" type and a medium-grain type with the excellent taste and cooking behaviour of a landrace such as Sierra Leone's Ngovie or of LAC 23. Moreover, to make African rice competitive, all rice researchers should lobby for improved milling operations at all levels.

To emphasize the need for a holistic breeding program to include quality, I quote from a 1985 article about a situation in Malaysia (Anonymous 1985):

> Heavy losses of the high yielding rice variety IR42 have led the Malaysian government to withdraw the seed. The variety was introduced into the country three years ago by the Muda Agricultural Development Authority because it was considered to have high resistance to the destructive red virus disease.
>
> Despite its [high yield] and resistance to red virus [it has] poor milling quality. After milling it produced only 38% of full grain rice.... Private millers ... stopped buying IR42 from farmers. The National Rice Board [finally] bought the paddy but incurred losses of nearly $20 million.

The lesson for African rice breeders should be clear.

DISEASES AND PESTS

Africa has rice pathogens and pests unique to Africa, as well as some in common with Asia and America (Soto and Siddiqui 1978; Buddenhagen 1983c). Many important viral diseases of Asia and Latin America are, so far, absent in Africa, although some of their insect vectors are present. Most insects causing damage to rice in Africa are indigenous species different from but closely related to those found in Asia (Soto and Siddiqui 1978).

These African rice pests (and some pathogens) have probably evolved with the wild species *Oryza barthii* and *O. longistaminata* and more recently have been associated with domesticated *O. glaberrima.*

But the Asian-evolved rice, *O. sativa*, which is the subject of all African rice-breeding programs, is encountering many African pests and pathogens for the first time. Thus, there are new-encounter disease and pest problems for the germ plasm from a different continent, often with unexpected susceptibility. For instance, rice yellow mottle virus (RYMV), native to Africa, was not even known until newly introduced HYVs from Asia revealed its presence by their extrasusceptibility.

The presence in Africa of unique pests and pathogens and the absence from Africa of many present in Asia provide African rice improvement programs with unique challenges and opportunities. These involve two basic themes that should influence breeding strategy.

First, the absence of many Asian problems means that all the resistances of Asia are not needed and that older Asian susceptible materials, very good in other respects, may be of use in African breeding programs and that Africa may profit from all of the Latin American materials, even the latest breeding lines with high yield and long grain, which are ignored in Asia because they lack resistances needed there. Thus, much stronger links with the Centro Internacional de Agricultura Tropical (CIAT) would be helpful.

The second theme is that on-site breeding is appropriate in African programs for the unique pathogens and pests present. The uniqueness may be entirely new pathogens and diseases for sativa rice, such as RYMV, "crinkle", and *Diopsis*, or it may be different biotypes or races of species found elsewhere. In either case, the indigenous African rice species and the ancient landraces offer unique and extensive germ plasm for assessment and analysis. Identification and introgression of genes for tolerance or resistance from the native species are exciting research opportunities. Moreover, much interesting research on the biology of the native pests and pathogens remains to be done.

As part of this theme, there is also the opportunity to devise screening and selection methods that will both fit a holistic breeding approach that includes stress and also work in relation to developing horizontal/durable resistance (Robinson 1980; Buddenhagen 1981a; 1983b; Johnson 1984).

The rice breeder and rice-breeding teams in Africa have a major opportunity to develop innovative approaches to their special circumstances wherein unique organisms are present and populations of many potential pests and pathogens are now low. I believe conventional breeding will favour increases in the populations of these pests (such as the various plant and leafhoppers) and will lead to spiraling insecticide use (Buddenhagen 1983a; Buddenhagen and de Ponti 1983). Innovation is needed. Breeders drawing on what is known about horizontal resistance (Bidaux 1978; Robinson 1980; Buddenhagen 1981; Buddenhagen and de Ponti 1983) and operating with a clear target of preventive breeding and of durable resistance can, I believe, develop new varieties that will neither result in new major epidemics from now-minor pests nor collapse due to resistance "breakdown" to now major pests. Whether any in Africa are willing to take up this challenge remains to be seen. I have not been heartened by the direction in recent years toward conventional methods that cannot be expected to provide either durability of resistance or prevention of the surge of minor pests to major pests. Possibly, however, some national programs in Africa have remained sufficiently independent to be innovative.

For example, stress (nutrient, cold, and drought) could be used as an aid in selecting for tolerance and resistance to several unrelated pathogens (Buddenhagen 1981b). Blast, along with other foliar fungal problems, and panicle disease are closely related to environment, and the relationship could be exploited by breeders (Bidaux 1978; Buddenhagen 1981b, 1983b).

Both the environmental conditions and biotype variability determine the host-parasite interaction and epidemic progression. The geographical location provides the setting for the environment and the pests. Therefore any strategy of breeding needs a focus on a location where the variety is intended to be grown. Maximum progress is to be made doing on-site breeding and selection with maximal host genetic diversity. Recurrent selection with recrossing, in situ where the problems are, combined with challenge designs allowing expression of minor genes, also to minor pests, offers, in my view, the best course to developing all-around good varieties.

Since the variability and biology of rice pests and pathogens are little studied in Africa, ancillary work to develop this knowledge should be part of any major centre concerned with African rice improvement. PhD students with good guidance are prime candidates for the work, and IITA is in a good position to foster such studies. There are many appropriate and relevant topics (Buddenhagen et al. 1972; Buddenhagen and Reddy 1972; Hsieh and Buddenhagen 1974, 1975). Of special interest are the indigenous and unique problems, for example the African rice viruses. Also, the finding of bacterial blight on wild rice in the sahel (Buddenhagen 1982a) — the disease apparently evolving separately from Asia — offers a challenging opportunity for research.

Before rejecting the need for innovative approaches and a new look at strategies in developing new varieties, one should appreciate that annual pesticide use amounts to about $7.3 billion worldwide. Even discounted for inflation, over the last 2 decades the changes in sales represent a doubling every 10 years (Buddenhagen 1983d). An annual growth rate of the chemical industry is projected at 4-5%. It should be obvious from these figures that plant breeders overall are not solving disease and insect problems. Moreover, strategies, and large investments by chemical companies, are predicated on the assumption that the future will reflect the past.

Will rice breeders and wetland development in Africa buck this worldwide trend? The challenges to the breeders, pathologists, entomologists, and agronomists are great. They, along with many others, have a tremendous opportunity to benefit African development.

Breeding for high and stable yields in Africa

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Abstract *International centres involved in varietal improvement of rice for the wetlands in Africa are the International Institute of Tropical Agriculture, the International Rice Research Institute, and the West Africa Rice Development Association. Collaboration among them is strong, particularly in the exchange of germ plasm and in varietal evaluation. At IITA the main objective is to incorporate, into high-yielding varieties of rice, resistance to the major biological and physical constraints, although consumer preferences for grain quality are also considered. IITA has identified or developed varieties for irrigated conditions as well as for hydromorphic soils and shallow swamps. Lowland varieties like ITA 212, ITA 222, and ITA 306 have performed well in national trials, and ITA 247 and ITA 249 are examples of varieties developed for soils with levels of iron that are toxic to many varieties. Working with staff at the national program in Cameroon, IITA breeders now have two cold-tolerant, high-yielding selections — B2161-C-MR-51-1-3-1 and IR7167-33-2-3. Lines selected at IITA are currently undergoing field testing in Niger for tolerance to rice yellow mottle virus.*

Three international centres are involved in developing rice varieties for the wetlands in Africa: IITA, the International Rice Research Institute (IRRI), and the West Africa Rice Development Association (WARDA). Varietal development work is also done by the national programs but generally not on the scale common in tropical Asia where rice is the major food crop and ranks high in research priorities. Strong collaboration exists among the centres, particularly in the exchange of germ plasm (Ng et al. 1983) and evaluation and testing of advanced breeding materials. For the wetlands, WARDA's activities focus on mangrove, irrigated, and deepwater/floating rices, whereas IITA's emphasis is on irrigated, hydromorphic, and shallow-swamp rice.

OBJECTIVES AND METHODS

For irrigated lowlands, short lodging-resistant varieties with good tillering ability and erect dark green leaves are considered ideal; they also perform well in hydromorphic soils not subjected to moisture stress. However, in less favourable hydromorphic soils and shallow swamps, slightly taller plants with good tillering ability, strong culms (for lodging resistance), and erect to droopy leaves are more suited to the fluctuating moistures and heavy competition from weeds.

At IITA, the major objective is to improve the resistance or tolerance exhibited by high-yielding varieties. For Africa in general, this means developing varieties with resistance to diseases such as leaf and neck blast as well as rice yellow mottle virus (RYMV) and insects such as the stalk-eyed fly (*Diopsis*), the striped borer, gall midge, and hispa (Alam et al. 1984). For individual countries, it means developing varieties with resistance to bacterial blight, sheath blight, leaf scald, and glume discoloration.

It also means breeding for tolerance to iron toxicity and cold, for, in the mid-altitude zones of Africa, such as parts of Cameroon, low temperatures, particularly at the reproductive stage of the plant, limit yields.

We are developing varieties that range from early maturing to late, and we are attempting to produce a grain that is widely accepted. Preferences among African rice consumers vary, but a recent survey done at IITA indicates that, in general, varieties that have an intermediate to high content of amylose are preferred (IITA 1985).

To find donors for the desirable characters, we are evaluating germ plasm available at the Genetic Resources Unit (GRU) of IITA as well as materials from IRRI, CIAT (Centro Internacional de Agricultura Tropical), and other breeding programs. GRU houses 5600 accessions of *Oryza sativa*, which were mainly collected from Africa, and 1941 accessions of *O. glaberrima* (Ng et al. 1983).

The evaluation of available and introduced germ plasm is the first step in identifying varieties with good potential yield, adaptability, and resistance or tolerance to diseases, insects, and adverse conditions. At IITA, this work is complemented by generation of breeding materials in crosses, intercrosses, and

Table 1. Promising selections of rice developed at IITA for lowland, irrigated conditions.

Selection	Maturation (days)	Plant height (cm)	Grain Length[a]	Grain Chalkiness[a]	Grain Amylose (%)
ITA 123	125	101	3	3	26
ITA 212	128	106	3	3	26
ITA 222	127	97	3	5	27
ITA 230	123	110	3	3	29
ITA 232	123	113	3	3	27
ITA 234	122	115	3	5	30
ITA 249	137	121	3	1	29
ITA 306	120	104	3	5	28

[a]Scoring follows the standard evaluation system for rice developed by IRRI (1980).

subsequent selection. This approach has proved fruitful for wetland rice and has provided a base for expanding hybridization and selection work against important stresses in Africa.

IRRIGATED RICE

Under irrigated conditions, many high-yielding semidwarf varieties have done well when introduced into Africa. For example, TOs 78 and TOs 103 were among those identified early as superior in evaluations conducted at IITA. These two selections were tested by the National Cereals Research Institute (NCRI, Nigeria) and were subsequently released as FARO 26 and FARO 27 for commercial production (Alluri and Alam 1983). Since then, high-yielding varieties that have been developed at IITA include ITA 123, ITA 212, ITA 222, ITA 230, ITA 232, ITA 234, ITA 249, and ITA 306 (Table 1).

These selections have all been entries in WARDA trials or in other trials outside IITA. In multilocational trials by the National Accelerated Food Production Project (NAFPP) in Nigeria conducted in 1983, ITA 212 ranked first among the entries tested (IITA 1984). In 1984, ITA 222 was one of the two highest yielding selections in the coordinated rice evaluation trials (CRETs) conducted at eight locations in Nigeria. It averaged 5.3 t/ha and was among the earliest maturing entries (Table 2). In Cameroon, the same year, its potential for high yields was confirmed in an advanced trial in Mbo Plain (Table 3). Along with two other lines — BKN 7033-33-2-2-3 and ITA 306 — it is now in the final stages of testing in the northern part of the country (Aboobaker Yacoubu, manager, Karewa Experimental Farm, Cameroon, personal communication, 1985).

Table 2. Performance of the most promising entries in the coordinated rice evaluation trial (CRET) — medium duration (average of eight locations in Nigeria), 1984.

Entry	Yield (t/ha)	Days to flowering	Plant height (cm)
IR8192-166-2-2-3	5.3	114	98
ITA 222	5.3	106	88
ITA 212	4.7	108	87
ITA 239	4.6	119	94
FARO 29 (check)	5.2	116	94

Table 3. Performance of selected entries in irrigated rice advanced trial in Mbo Plain, Cameroon, 1984 (IITA 1984).

Entry	Yield (t/ha)	Days to flowering	Plant height (cm)
ITA 222	5.4	105	90
ITA 121	4.9	103	85
Cisadane	4.7	111	94
IR3273-339-2-5	4.7	107	90
IR54	4.6	108	89
Tainan 5 (check)	3.5	93	96

HYDROMORPHIC AND SHALLOW-SWAMP RICE

Results obtained so far at IITA have shown that, in the absence of stress, many improved varieties developed for irrigated paddies perform well in hydromorphic soils (IITA 1982; Alluri and Alam 1983). For example, ITA 121, ITA 212, ITA 230, and ITA 306 (IITA

Table 4. Promising entries in trials conducted under irrigated and hydromorphic soil conditions, 1984 dry and wet seasons, IITA (Ibadan, Nigeria).

	Grain yield (t/ha)			
Entry	Irrigated dry season	Irrigated wet season	Hydromorphic soils, wet season	Mean
B9894-22C-5M-5-1-1	7.4	5.0	6.5	6.3
TOx 960-42-1	7.7	5.1	6.0	6.2
TOx 915-101-1	8.1	4.1	5.2	5.8
SiPi 692033	6.9	5.0	5.4	5.7
32 Xuan 50	7.5	4.7	5.2	5.7
IR18348-36-3-3	7.0	4.4	5.4	5.6
IR36 (check)	6.7	4.2	2.8	4.6
TOs 103 (check)	7.6	4.3	3.5	5.2

1982, 1985) have all done well in hydromorphic soils, and ITA 247, an intermediate-stature selection has shown good performance in shallow swamps (IITA 1982; Alluri and Alam 1983). In the 1984 trials, highest yields during the wet and dry seasons were obtained from B9894-22C-5M-5-1-1, TOx 960-42-1, TOx 915-101-1, and SiPi 692033 (Table 4). TOx 960-42-1 is a selection that combines high-yield potential, resistance to blast, and long slender grains.

Starting in 1984, we made crosses specifically to develop varieties for hydromorphic soils and shallow swamps. Varieties known to be adapted to rainfed environments as well as donors with suitable plant type, yield potential, and resistance were involved in the crosses. We are now evaluating about 1000 F_3 lines selected from the progenies of the initial crosses.

To enhance recombinations and to supplement the output from conventional crosses, we established a composite population based on genetic male sterility. Twelve parents were involved in crosses with six sterile lines introduced from IRRI. Parents included those adapted to rainfed environments and exhibiting good plant type and yield potential, but the emphasis was on tolerance to soils with toxic levels of iron. Tolerance to RYMV will be introduced into the pool when a suitable donor has been identified. The crosses were made in early 1984, and the population is now in the second cycle of intercrossing.

BREEDING FOR SPECIFIC STRESSES

IRON TOXICITY

Soils with levels of ferrous ion that are toxic to rice occur in many inland valleys and irrigated fields in Africa (Benin, Burkina Faso, Côte d'ivoire, Liberia, Nigeria, Senegal, and Sierra Leone) (Virmani 1979; IITA 1984). Iron toxicity has been reported to reduce yields 12-88%, depending on rice variety and intensity of toxicity (Gunawardena et al. 1982). We have observed 100% reduction in yields from nontolerant lines.

The first variety with tolerance to iron-rich soils was developed and released through collaboration between the Liberia Rice Project and IITA: it was called Suakoko 8 (Virmani 1979) and had been selected from a line derived from a cross between Siam 25 and Malinja introduced from Malaysia. Suakoko 8 yielded nearly the same as IR5 in soils where iron toxicity was not a problem but yielded about 20% more than IR5 under toxic conditions. Along with Gissi 27, a variety from Liberia identified as tolerant, Suakoko 8 was used as a source for tolerance in early work on rice in IITA.

The locus controlling tolerance in Suakoko 8 appears to differ

Table 5. Lines with a score lower than 6 in screening for susceptibility to iron toxicity (IRRI 1980) in rice transplanted in Suakoko, Liberia, 1983–84.

Entry[a]	Weeks after transplanting 2	4	6	8	10
TOx 960-31-1	2.0	3.0	3.2	5.0	4.0
TOm 2-65	1.0	2.0	1.5	2.0	2.0
TOx 960-9-2	0.0	1.0	1.0	2.5	3.0
CIAT 16404	2.0	2.5	3.0	4.0	4.0
TOm 2-31	1.0	1.2	1.2	4.2	4.0
CIAT 21528	0.8	1.8	2.5	3.2	3.3
TOm 2-38	0.8	1.5	2.5	2.5	—
TOm 2-17	0.0	1.5	2.5	2.5	—
TOm 2-15	0.8	1.8	2.8	3.2	—
TOm 2-66	0.2	1.0	3.8	3.0	—
TOx 711-17-4	0.8	0.8	3.0	3.5	—
AD 9246	2.0	3.0	3.0	5.0	—
TNAU 7893	1.0	1.0	2.0	3.0	—
IR13240-82-2-3-2	2.0	1.0	1.0	3.0	3.0
BR161-2-3-58	1.0	1.0	2.0	3.0	3.0
TOx 1838-1-3	1.0	1.0	2.0	3.0	3.0
TOx 903-2-1	1.0	1.0	2.0	2.0	2.0
IR13538-48-2-3-2	1.0	2.0	2.0	2.0	3.0
BR24-2-1	1.0	1.0	1.0	2.0	3.0
ITA 302	1.0	1.0	2.0	3.0	3.0
Suakoko (resistant check)	1.1	1.9	2.2	2.9	3.2
IR26 (susceptible check)	2.8	3.2	6.5	8.0	8.5

[a]TOm 2 lines were derived from irradiated Gissi 27 done for IITA by the University of Ibadan, Nigeria.

from that in Gissi 27, and both have been used in crosses with diverse high-yielding and improved varieties like IR42, IR46, FARO 27, IR9729-67-3, and ITA 306.

One particularly successful cross was TOx 711 (IR5 × Suakoko 8) from which several promising lines have been selected, including ITA 239, ITA 244, ITA 245, ITA 247, and ITA 249. In a trial conducted at Ito-Ikin, one of the iron-toxic sites in Nigeria, ITA 247 produced 3.0 t/ha compared with 1.9 t/ha for the check variety (FARO 15) (IITA 1983).

IITA, WARDA, and CARI (Central Agricultural Research Institute, Liberia) recently initiated a collaborative research project on iron toxicity. The IITA liaison scientist at WARDA who is a plant breeder is in charge of the project. Breeding lines are screened at Suakoko, Liberia, and some have proved particularly promising (scoring was done at 2, 4, 6, 8, and 10 weeks after seedlings were transplanted) (Table 5).

COLD TOLERANCE

Breeding for cold tolerance began in 1982 with the implementation of the National Cereals Research and Extension (NCRE) Project in Cameroon and the assignment of an IITA plant breeder to the project. The aim is to provide suitable varieties to large parastatal organizations growing rice in Cameroon.

The research will also benefit other mid-altitude zones of east, central, and southern Africa. Nontolerant varieties of rice grow slowly and are characterized by poor panicle exsertion as well as sterile spikelets.

In Cameroon, a large area where rice is grown is affected by low temperatures. The site where the project work is being done is Ndop Plain in North West Province at an elevation of about 1100 m where about 2000 ha are planted to irrigated rice.

Initially a large number of varieties and advanced breeding lines were introduced and evaluated. Most of the materials were from the International Rice Testing Program's yield and observational nurseries, the international rice cold tolerance nursery, and the international rice blast nursery.

The most promising introductions were B2161-C-MR-51-1-3-1, B29838-51-1-2-1, IR2061-522-6-9-1, IR54, and IR7167-33-2-3 (IITA 1985). Very likely to be released by the parastatal organizations is IR7167-33-2-3. In 1984–85, IITA sent the project in Cameroon additional material — 10 F_2 populations and 170 lines derived from crosses involving cold-tolerant and blast-resistant parents.

RICE YELLOW MOTTLE VIRUS

RYMV constitutes a threat to development and expansion of wetland rice production throughout subsaharan Africa. First described in Kenya (Bakker 1970) it has since been reported in Burkina Faso, Côte d'ivoire, Niger, Nigeria, and Sierra Leone (Raymundo and Buddenhagen 1976; Alam et al. 1984).

From extensive screening done by pathologists at IITA, varieties showing high levels of tolerance to RYMV have been identified and are being used as donors in the breeding program (IITA 1983, 1985). Included among these are Moroberekan, LAC 23, ITA 235 (all three of which are for upland cultivation), and CT 19, a semidwarf variety from India. These were crossed with elite varieties and lines that were superior in IITA and international trials: ITA 121, ITA 212, ITA 222, ITA 230, ITA 306, IR2042-178-1, IR21015-80-3-3-1-2, IR9729-67-3, IR9828-91-2-3, and Taichung Sen Yu 285.

Progenies from these crosses are now in F_3 and F_4 generations and are being evaluated further for resistance and agronomic traits; in fact in response to a request from the rice program in Niger, 300 F_4 lines have been sent for field testing.

INSECT PESTS

Some 6800 rice varieties have been tested in the screenhouse and in the field for resistance to the major insect pests (Alam et al. 1984). ITA 121 and DJ 12-539-2 are being used as sources of resistance to stalk-eyed fly, and the variety Eswarakora for resistance to gall midge.

The breeding experience from Asia

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Abstract *Rainfed lowlands, constituting about 28% of the world's riceland, are the nonirrigated areas where soil is flooded (maximum 50 cm deep) during a portion of the growth cycle. Predominant stresses include drought, short-term submergence, long-term stagnant flooding, and adverse soil conditions. For the purposes of varietal improvement and crop management, rainfed lowland rice has been divided into five categories: shallow, favourable; shallow, drought-prone; shallow, drought and submergence prone; shallow, submergence prone; and medium-deep, waterlogged. Improved cultivars for the rainfed lowlands should be medium to tall, with appropriate growth duration (including photoperiod sensitivity), tolerance to physicochemical stresses, and resistance to prevalent insects and diseases. At IRRI, the improvement program for rainfed lowland rice emphasizes an interdisciplinary and international approach. Early generations of populations are screened at IRRI for key traits, and advanced lines are tested at representative sites on farms. Promising lines are entered in the appropriate nurseries of the International Rice Testing Program (IRTP) for international evaluation and distribution. Farmers' fields are selected to represent the various rainfed lowland types so that researchers can develop low-cash inputs and management practices while evaluating advanced breeding lines. Careful environmental characterization of the sites allows extrapolation of results to other rainfed areas.*

A major review of the systems for classification of rainfed environments was recently undertaken by an international committee (IRRI 1984). A total of 24 systems of terminology were explored and correlated. As a result of this study, the committee proposed a general terminology for rice environments (Table 1) for international usage (IRRI 1984).

Table 1. Terms used to classify rice-growing environments (IRRI 1984).

Rice-growing environment	Subdivisions
Irrigated	Favourable temperature Low temperature, tropical zone Low temperature, temperate zone
Rainfed lowland	Shallow water, favourable temperature Shallow water, drought prone Shallow water, drought/submergence prone Medium-deep water, waterlogged
Deepwater	50-100 cm deep >100 cm deep
Upland	Long growing season, favourable soil (LF) Long season, unfavourable soil (LU) Short season, favourable soil (SF) Short season, unfavourable soil (SU)
Tidal wetland	Perennially fresh water Seasonally or perennially salt water Acid sulfate soils Peat soils

The classification includes rainfed lowlands in which the crop is not irrigated but the soil is flooded for at least a portion of its cycle, the water being a maximum 50 cm deep (IRRI 1984). This broad definition distinguishes a major class of ricelands estimated to cover about 28% of the rice area of the world.

The rainfed lowlands were subdivided into five broad categories for which specific varieties and cultural practices are needed. The target environments were distinguished by the prevalent water regimes and stresses of inadequate or excessive moisture:

- Rainfed, shallow, favourable environments were conceptualized as those areas in which drought or submergence is not a serious constraint to the use of varieties and management practices that are essentially similar to those in fully irrigated rice systems.
- Rainfed, shallow, drought-prone environments are those that experience frequent and severe water stress whether the rainy period is short (90-110 days) or long (and highly uncertain). The former is common in central and eastern India, the latter in Bangladesh and northeast Thailand. Many of the hydromorphic ricelands of East and West Africa probably fall into this class, with surface water accumulating for short periods. When the surface is not flooded the water table tends to remain in the root zone for extended periods.

- Rainfed shallow, drought- and submergence-prone ricelands experience both water stress and short-term flooding that damages or destroys crops when specifically adapted varieties are not used.
- Rainfed shallow, submergence-prone areas frequently experience short-term flooding, with otherwise favourable water regime. Ricelands in irrigation systems and river floodplains where drainage is constricted or overflow occurs are frequently subjected to submergence.
- Rainfed, medium deep, waterlogged ricelands accumulate water at depths of about 25–50 cm for a substantial portion of the growing season. The crop may be submerged for short periods and grows slowly because of the stagnant water.

Ricelands that experience sustained water depths greater than 50 cm are considered deepwater and are therefore not included within rainfed lowland. This classification has been elaborated by Khush (1984) who discussed the attributes of current varieties and the general directions in breeding improved materials for the respective conditions.

Since many local terminologies for the types of rainfed lowland are in use in different countries, a correlation of the prevalent terms is desirable. In eastern India rainfed rice environments are designated in terms of high, medium, and low lands emphasizing the strong influence of landscape position. Garrity (1984) attempted to correlate (Table 2) the WARDA (1980) rice environmental classification with the terminology adopted by IRRI (1984). More work is needed, however, so that rice scientists from Africa and Asia can communicate and work together effectively.

One of the major purposes of this type of broad agroecologic zoning is to assist breeders to set priorities and objectives. Selection of optimal test sites and interpretation of multisite trials can also be enhanced by the appropriate characterization of the test sites and knowledge of the respective environments they represent. Further work at IRRI has been undertaken to delineate and quantify these categories and reveal the relevant diversity within each category. For example, a data base was constructed to define the climatic conditions and soils in the production regions of rainfed lowland rice in Asia. The regional maps of Huke (1982) were used as the source of information on location of the ricelands. The analysis included 30.3 Mha of shallow rainfed lowland rice.

Drought, however, is a difficult parameter to quantify. The "drought-proneness" of a site is estimated as the interaction of the edaphic features (slope and soil texture) with climatic features (rainfall and growing season).

The propensity for submergence or flash flooding is a function of water accumulation as a result of either heavy rainfall (climatic

Table 2. Comparison of terms used in IRRI classification and three other systems based on general surface hydrology (WARDA 1984), physiographic source of water to the landscape (Moormann and van Breemen 1978), and terrain (Bruce and Morris 1981).[a]

IRRI (1984) equivalent	WARDA (1980)	Moormann and van Breemen (1978)	Bruce and Morris (1981)
IRRIGATED	Freshwater cultivation with complete water control	Irrigated (4)	Alluvial terrace*; interhill miniplain*; interhill basin*
RAINFED LOWLAND			
Shallow			
Favourable		Pluvial (2,3)*; phreatic (1,2,3)*	Alluvial terrace*; interhill miniplain*; interhill basin
Drought prone	Freshwater cultivation without water control	Pluvial (1,2)*; phreatic (1,7)*	Interhill miniplain; alluvial fan
Drought and submergence prone	Freshwater cultivation without water control	Pluvial (1,2)*; phreatic (1)*	Alluvial terrace*
Submergence prone		Pluvial (2,3)*; phreatic (2,3)*; fluxial (2,3)*	Backswamp*; alluvial terrace*
Medium deep		Phreatic (5); fluxial (5)	Backswamp*
DEEPWATER			
50–100 cm	Freshwater cultivation without water control	Phreatic (6)*; fluxial (6)*	Swamp*
>100 cm	Floating rice	Phreatic (6)*; fluxial (6)*	Swamp*
UPLAND	Upland rice	Pluvial	Hill-slope
TIDAL WETLAND	Mangrove rice	Fluxial (8)	Tidal swamp

[a]* = partial taxon; numbers in parentheses indicate the flooding regime: 1 = shallow, irregular, brief flooding; 2 = shallow, irregular, prolonged flooding; 3 = shallow, continuous uncontrolled flooding; 4 = shallow continuous flooding controlled by irrigation; 5 = shallow to moderately deep seasonal flooding; 6 = deep seasonal flooding; 7 = moderately deep to shallow flooding after recession of deep floods; 8 = tidal flooding.

submergence) or overflow of river water from a different area (fluvial submergence). Areas climatologically prone to submergence may be predicted on the basis of rainfall and topographic data and those submerged fluvially should be clear from data on river levels and topographic conditions.

To estimate the threat of submergence, researchers need to develop and test procedures to predict how these factors interact, distinguishing timing, depth, and duration of submergence.

Bruce and Morris (1981) developed a land classification for a major river valley in the Philippines that permits a limited but objective evaluation of the correspondence between terrain units and flooding propensity and depth (Table 2). However, no other work specifically addresses mapping of the submergence threat. Therefore, estimates of the submergence-prone areas of shallow rainfed rice are not yet possible.

SOIL FERTILITY CONSTRAINTS

Some of the rainfed lowlands in Asia are fertile so that rice cultivators need add only moderate amounts of nitrogen and, less frequently, phosphorus and potassium fertilizers. However, other major areas experience a range of chemical imbalances that seriously affect productivity and influence varietal adaptation. Salinity, alkalinity, toxic levels of iron, phosphorus deficiency, zinc deficiency, and organic and acid sulfate conditions are the major problems.

To estimate the areas affected, we correlated the rainfed lowland rice dot map of Huke (1982) with FAO–Unesco maps of soils in South and Southeast Asia. The fertility capability classification (FCC) system was used to interpret the fertility constraints (Sanchez and Buol 1985).

The analysis indicated that slightly less than one-half of the shallow rainfed lowland rice in South Asia is grown on soils expected to be without major soil constraints. For Southeast Asia the corresponding figure is only one-fourth. Soils with low cation exchange capacity are common in both regions, necessitating exacting N management.

In areas where the adjacent uplands are iron-rich, the valleys exhibit toxic levels of iron. About 4.4 Mha have soils capable of fixing large quantities of phosphorus, a characteristic associated with P deficiency and Fe toxicity. Among soil constraints, the predominance of phosphorus-fixing soils suggests that tolerance to P deficiency is a character that should be given serious attention in breeding efforts.

The cultural type classification described (Table 1) defines rainfed lowland environments in terms related to breeding objectives: the water regime determines stresses (i.e. drought, submergence, and stagnant flood or medium deep) for which tolerance is required as well as the appropriate maturation, although the latter depends also on the cropping system.

A survey of rice breeders in South and Southeast Asia (Mackill 1984) was recently conducted to set breeding objectives for rainfed lowland rice. Intermediate plant height (100–130 cm) was favoured in most cases, but taller varieties (120–150 cm) were preferred in more than 40% of all cases — usually as a solution to submergence, stagnant flooding, or delayed transplanting. Early maturity was preferred mostly in drought-prone areas. In general, breeders felt that disease and insect resistance was the most important breeding objective for rainfed lowland rice.

The disease and insect problems did not appear to be related to the type of rainfed lowland rice. The results followed closely those of an earlier survey of Asian rice breeders (which included all types of rice) by Hargrove and Cabanilla (1979), although brown spot (caused by *Cochliobolus miyabeanus*) and sheath rot (*Sarocladium oryzae*) have gained prominence. Breeding objectives for rainfed lowland conditions are similar to those for irrigated conditions except that a different plant type and different tolerances to stress are required.

THE BREEDING PROGRAM AT IRRI

At IRRI before 1976, cultivars and breeding lines suitable for rainfed lowland conditions were mostly a spinoff from the breeding program for irrigated rice. The second cultivar released by IRRI, and designated IR5 in 1967, was recommended for infertile soils because of its intermediate plant height. While not receiving the attention given IR8, IR5 became popular in many rainfed areas and has been used extensively as a parent in rice-breeding programs. A sister line of IR5, named Pankaj in India, is still widely grown in the eastern lowlands of that country.

In 1975, two varieties were released by IRRI for rainfed lowland conditions: IR32, a long duration (140–145 days) cultivar, and IR34, a medium duration cultivar with intermediate height. More recently, two IRRI breeding lines were released as IR46 and IR52 by the Philippine government for rainfed lowland conditions. IR46 has shown high and stable yields in international trials and has given excellent progeny as a parent in the rainfed lowland breeding program. IR52 has a good level of drought tolerance but is susceptible to blast.

In 1977, the breeding program at IRRI was divided into six major categories for attention by plant breeders — irrigated, rainfed lowland, deepwater, adverse soils, upland, and cold areas. Objectives set for the rainfed lowland program included intermediate height, medium to late duration, disease and insect resistance, drought tolerance, good seedling vigour, tolerance of delayed transplanting, and good tillering ability in standing water. Cultivars such as C4-63, Pelita I-1, IR5, and IR34 were used as sources of intermediate stature. Among the breeding lines identified for rainfed lowland conditions, IR4219-35-3-3 (IR2061-213/IR480-5-9-3) was considered a prototype of the high-yielding, rainfed lowland plant type (Coffman and Nanda 1980).

In 1977, the IRRI Long Range Planning Committee recommended that rainfed rice research (particularly rainfed lowland) receive heavy emphasis. The next year, about 50% of all the crosses made at IRRI were for rainfed lowland conditions. From the beginning of the program, collaborative research was emphasized (Coffman and Nanda 1980). The major rice-growing areas of the Philippines were clearly not representative of the vast rainfed lowlands of South and Southeast Asia. To select cultivars with stable yields in variable environments, we sent F_2 populations to the breeding programs of Bangladesh, Thailand, Indonesia, Burma, and India (West Bengal). The seeds of selected populations were returned to IRRI for redistribution to other sites (IRRI 1980).

BREEDING OPERATIONS

The current approach to developing improved varieties for rainfed lowlands involves a large program of hybridization; selection of F_2, bulk populations and pedigree lines under both stressed and unstressed conditions; and simultaneous screening of pedigree lines for disease and insect resistance, grain quality, and stress tolerance. The parents (Table 3) used can be classified as popular traditional and improved cultivars; donors for specific traits; and improved breeding lines with intermediate height and high, stable yields.

In multiple crosses where the parents differ widely in height and duration, F_2 families are grown in individual rows to avoid excessive competition. Although the modified bulk method has been used to some extent, the pedigree method of breeding from the F_3 generation has been favoured at IRRI because of the ability to screen the pedigree lines simultaneously in special nurseries (Table 4) (Khush and Coffman 1977; Jennings et al. 1979). Most pedigree rows are grown at the IRRI farm under relatively favourable conditions but with natural and augmented disease and insect pressure. In some cases, pedigree rows have been grown under rainfed lowland conditions in farmers' fields in the Philippines. The pedigree rows are usually bulked in the F_5 or F_6 generation when they become uniform for agronomic and other characters.

Some new breeding approaches have been used in the rainfed

Table 3. Traits of selected cultivars used as parents in the rice-breeding program at IRRI.

Cultivar	Origin	Photoperiod sensitive	Other traits
ARC 11554	India	+	Resistant to rice tungro
Badshabhog	Bangladesh	+	Consumer-accepted grain
BKNFR76106-16-0-1-0	Thailand		Tolerant to submergence
Black Gora	India		Early, vigorous, drought tolerant
BR319-1	Bangladesh		Vigorous, good plant type
Cisadane	Indonesia		Resistant to bacterial blight
CR1009	India	+	Semidwarf
Dular	India		Drought tolerant
GEB 24	India	+	Adaptability, consumer-accepted grain
IET1444	India		Tolerant to drought and phosphorus deficiency
IR21178-43-1-2-2-2	IRRI		Tolerant to drought
IR26702-25-1	IRRI		Tolerant to submergence
IR33153-3	IRRI		Tolerant to drought
IR52	IRRI		Tolerant to drought
Janki (Chenab 64-117)	India	+	Tolerant to drought and submergence
Jhingasail	Bangladesh	+	Wide adaptability
Kamakyi	Burma	+	Late, suitable for medium-deep water
Khao Dawk Mali 105	Thailand	+	Consumer-accepted grain, tolerant to poor soils
Mahsuri	Malaysia		Wide adaptability, tolerant to poor soils, consumer-accepted grain
Nam Sagui 19	Thailand	+	Tolerant to drought and submergence
Niaw Sanpah Tawng	Thailand	+	Glutinous, high yielding
Pankaj	India		Excellent plant type, suitable for medium-deep water
Patnai 23	India	+	Tolerant to salinity, consumer-accepted grain
PM1121	India		Tolerant to drought
5173	Colombia		Resistant to blast, good plant type

Table 4. Location and department in charge of evaluation of pedigree lines for traits in IRRI breeding program for rainfed lowlands.

Trait	Location	Department
Resistance to blast	Blast nursery	Plant pathology
Photoperiod sensitivity	Dry-season nursery	Plant breeding
Tolerance to drought	Dry-season nursery	Agronomy/IRGC
Resistance to rice tungro virus	Field	Plant pathology/ plant breeding
Resistance to bacterial blight	Field	Plant pathology
Resistance to brown planthopper	Greenhouse	Entomology
Resistance to green leafhopper	Greenhouse	Entomology
Tolerance to salinity	Greenhouse	Soil chemistry
Tolerance to submergence	Greenhouse tanks	Plant physiology
Amylose content	Laboratory	Plant breeding
Gelatinization temperature	Laboratory	Plant breeding
Grain appearance	Laboratory	Plant breeding

lowland program. Specifically, the rapid generation advance (RGA) system has been used when photoperiod sensitivity is an objective (Vergara et al. 1982). This system is used only with a few high-priority populations because of the limited space in the RGA screenhouse. We usually select the F_2 populations in the field to eliminate the undesirable plant types before putting the F_3 populations through RGA. Population improvement is also being used. The male sterile gene of IR36, an induced mutant, was introduced into breeding lines with a rainfed plant type, and several populations have been formed with specific objectives such as drought and submergence tolerance.

International collaboration is emphasized in the rainfed lowland program. During the past 3 years, we have sent segregating populations and advanced lines to interested scientists in Bangladesh, Burma, Kampuchea, India, Laos, Malaysia, Nepal, Sri Lanka, Thailand, and Vietnam as well as to Nigeria, Rwanda, Senegal, Tanzania, and Uganda. F_2 populations with appropriate parents are sent upon request to national programs for on-site selection. In some cases we receive seed of plant selections made in the national programs. Recent work has focused on grouping areas by the required breeding objectives.

In 1982, a collaborative breeding program was initiated to develop varieties for the rainfed areas of northeast Thailand. F_2 populations of crosses made at IRRI began to be grown in northeast Thailand, and the seeds from the selected plants returned to IRRI for further screening. The selections in Thailand are made during the

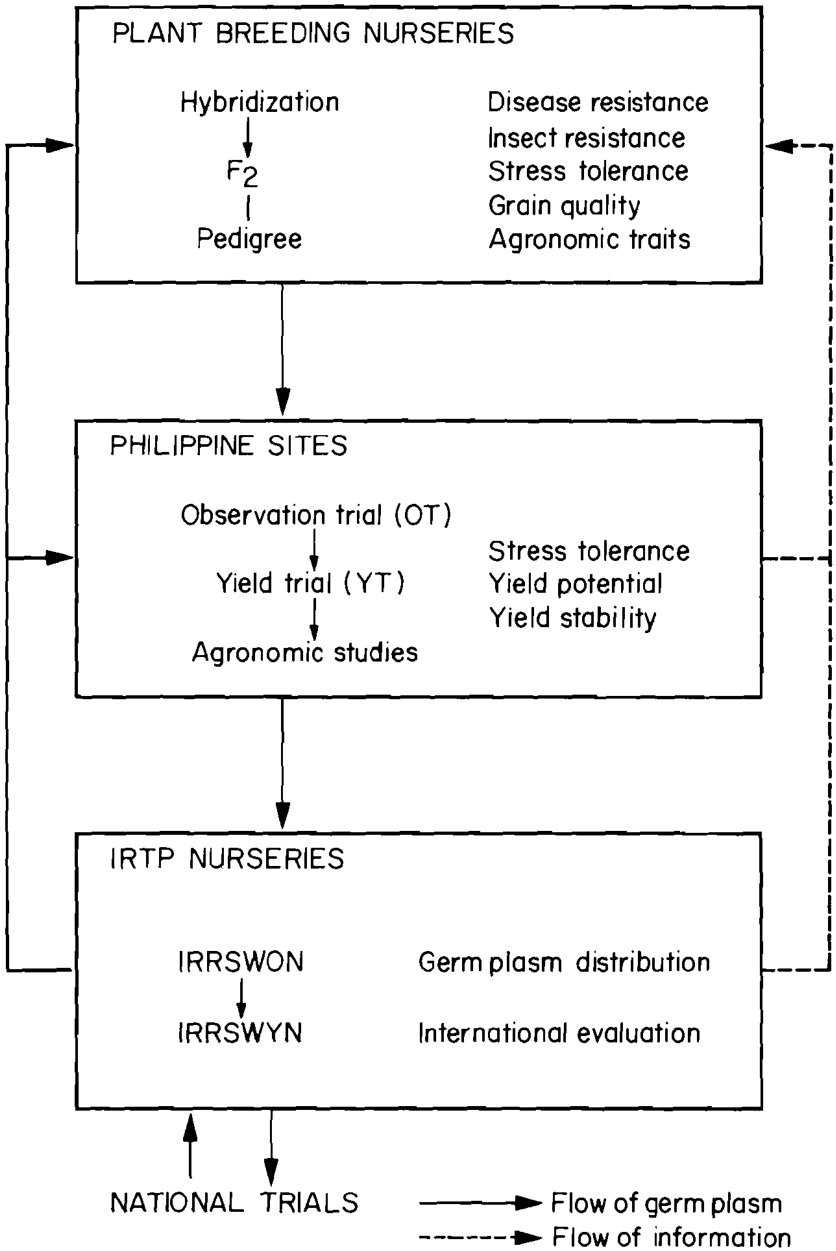

Fig. 1. Flow of breeding materials and information in IRRI's program to improve rice for the rainfed lowlands.

main wet season (June-November), and the IRRI nurseries are seeded by mid-December so that the photoperiod-sensitive lines will flower by April. With this "shuttle breeding" approach, two generations can be grown per year and selected under diverse conditions.

EVALUATION OF ADVANCED BREEDING LINES

After uniform pedigree lines are bulked, they are evaluated at several Philippine testing sites under a variety of environmental conditions. The first stage is an unreplicated observational trial (OT) of several hundred entries. Those entries that perform well at all sites are included in the replicated yield trial (YT) in the following season. The entries that perform best in the yield trials, particularly in the most stressed sites, are evaluated in different countries through the International Rice Testing Program (IRTP). The general flow of breeding materials is, thus, from the plant breeding nurseries to the OTs and YTs at the Philippine sites, and then to IRTP (Fig. 1). Superior entries in IRTP from other breeding programs are included in the hybridization program and appropriate trials.

Initial selection of varietal testing sites in the Philippines is based on the correlation of environmental characters with those found in the major rainfed lowland areas. Each site is chosen to represent a unique combination of hydrologic, soil, chemical, and biologic stresses as related to the major ecosystems identified by the macro level classification.

Greatest attention is currently given to the drought-prone rainfed lowlands. In Asia, this class of ricelands falls into two distinct subclasses (Table 5) that correspond to widely divergent characteristics and agronomic practices.

Table 5. Characterization of the two subclasses of drought-prone rainfed lowlands.

	Drought prone class	
	I	II
Rainy period	Short, monomodal	Long, erratic, bi-modal
Characteristics		
Varietal	Photoperiod insensitive, early to very early maturity	Photoperiod insensitive, medium to late maturity
Agronomic	Direct seeded	Transplanted
Distribution	Madhya Pradesh, India; western Nepal; central Burma	North and northeast Thailand; Cagayan, Philippines

The drought-prone areas (DPA) nursery, which was initiated in 1979, is currently tested at five locations, although testing locations change over time as we sharpen our understanding of the major target condition.

For example, the physical environment of IRRI's Cebu site showed a high degree of correlation with sites in the vast rainfed lowlands of northeast Thailand, where tall photoperiod-sensitive varieties are superior. However, varietal performance at the Cebu site was negatively correlated with performance in northeast Thailand, suggesting that the two environments are far more divergent than was earlier assumed.

AGRONOMIC RESEARCH

The general research strategy of IRRI's rainfed lowland rice team emphasizes strong links between the breeding program and the on-location evaluation of breeding materials as early as practicable after hybridization. For this reason, the breeders and agronomists work closely together.

One role of the agronomist is to develop and manage field laboratory sites that represent the target ecosystems and to strengthen the performance testing, providing feedback to the breeding program.

In the disadvantaged rice environments, varietal response to management inputs is often low and variable. Risk of drought and flooding discourages farmers from spending cash on inputs for the rice crop. Agronomists, therefore, are attempting to identify constraints and to develop realistic management solutions within the means of cash-poor farmers.

Emphasis is placed on techniques that can substitute for purchased inputs. Encouraging results have recently been obtained with crops grown as green manure during the long fallow (2–3 months) after the rains begin and before the rice crop is transplanted. This growing period allows substantial nitrogen to be fixed in the soil in suitable ecologic systems.

Most farmers in the rainfed lowlands in Asia transplant seedlings 30–60-days-old because water is not available in the field at planting time (Mackill 1984). A single rice crop (photoperiod sensitive) is usually grown. In general, however, when modern rice varieties are transplanted this late, yields are drastically reduced. Fortunately, genotypes that are insensitive to late transplanting can be identified (Malabanan et al. 1985), and these may be the basis for increasing rice yields in many stress-prone areas. A program to evaluate the breeding materials for seedling age insensitivity is in progress.

Crop-establishment practices differ remarkably among rainfed lowland areas. Seeding methods depend on the rainfall pattern and the drainage characteristics of the site. There are three major seeding methods with many variants:

- Dry seeding;
- Wet seeding; and
- Transplanting.

These systems have been refined through centuries of use.

Dry seeding has advantages in areas with a short growing season since time is gained in establishing the crop early. It is also advantageous in zones where excess flooding is expected early in the season. Early establishment improves the chances for the crop to withstand the flooding. In India broadcasting proceeds from the fields at the lowest topographic position upward to the high lands (i.e., from very deep water to deep water to medium deep to shallow). The land is prepared after harvest of the previous rice crop or by plowing with the premonsoon rains. When land preparation is not possible before the monsoon rains arrive, broadcasting is done on moist soil.

Wet seeding of pregerminated seeds on level land that has been puddled is practiced in limited areas. Success depends on the specific characteristics of the dry to wet transition at the onset of the monsoon and on the adequacy of surface drainage (Morris and Zandstra 1979).

Transplantation is increasingly practiced in areas where water management is improving. Comparisons of broadcasting versus transplanting have given situation-specific results. In many cases yields differ little between the two practices. In Asia, whenever transplanting is possible, it tends to be the predominant practice because it minimizes competition from weeds. Seedlings are kept in the seedbed until there has been adequate rainfall for land preparation.

Much work has been done in studying and comparing rice-planting practices. Rarely has the environment been monitored adequately to make the results valid for extrapolations. Methods to characterize the onset and termination of rainfall are being developed and may allow researchers to determine systems for optimal crop establishment (Morris and Zandstra 1979).

Many rainfed lowlands are potentially two-crop areas. However, the rice variety (particularly growth duration) and the management system usually need to be adjusted in order that the potential can be realized. The length of hydrologic year ultimately determines the cropping period available (Morris et al. 1984). The dynamics of the water regimes, particularly during the transition periods of onset and recession of the rains, determine the feasible choices for crops.

Table 6. Entries (by year) in the international rainfed rice shallow water observational nurseries (IRRSWON 1978-84) that received good ratings overall.[a]

Year	Growth duration	Entries
1978	Medium	IR5677-17-3-1
1979	Medium	IR14632-181-1, IR14753-49-2, IR14753-66-3, IR14753-133-2, IR4215-301-2-2-6, *IR4819-77-3-2*, Nam Sagui
1980	Medium	BR10, BR51-282-8, IR10781-75-3-2, IR13146-41-3, IR13146-45-2-3, IR13564-95-1, *IR4819-77-3-2*, *IR4829-89-2*, Mahsuri, Pelita I-1
1981	Early	IR3880-10, IR8608-82-1-3-1-3, IR9698-16-3-3-2
	Medium	IR13146-13-3-3, IR13257-46-1E-P1, IR14497-15-2, IR14753-86-2, IR14875-98-5, IR2987-13-1, IR46, *IR4819-77-3-2*, *IR4829-89-2*, IR9852-22-3
1982	Medium	IR13146-45-2-3, *IR15853-89-7E-P3*, IR19083-22-2-2, IR19256-88-1, *IR21141-24-2*, *IR46*
1983	Medium	*IR15853-89-7E-P3*, IR21037-2-1-2E-P1, *IR21567-16-3*, *IR21567-18-3-1*, *IR4829-89-2*, IR54, RP975-109-2
1984	Early	IR5853-198-1-2, *IR21567-18-3-1*
	Medium	IR21836-90-3, *IR13146-45-2-3*, *IR21141-24-2*, *IR21567-16-3*, IR28941-164-1-5, IR31429-14-2-3, *IR46*

[a]Varieties that are italicized were among the best entries in more than 1 year.

INTERNATIONAL TESTING

IRTP being coordinated by IRRI provides a mechanism for exchange of genetic materials among rice-growing countries around the world and for their evaluation in different agroecologic environments. Among the several nurseries organized under the auspices of IRTP for the various target environments and stresses are yield and observational nurseries designed for evaluation under shallow-water lowlands. These nurseries are designated as international rainfed rice shallow water yield nursery (IRRSWYN) and international rainfed rice shallow water observational nursery (IRRSWON). IRRSWON was initiated in 1978 and IRRSWYN in 1981. The test entries included semidwarf and intermediate statured lines with a wide range of maturity, either sensitive or insensitive to daylength. More than 50 sites in South and Southeast Asia and Africa and Latin America now participate in these nurseries (Alluri et al. elsewhere in this volume).

During 1978–84, more than 50 entries received good overall ratings in the observational nurseries (Table 6); a few performed well under stress:

- The nursery (1980) at Barisal, Bangladesh, was under tidal submergence (15 cm–1 m) during the growth period; most entries were given scores of 7–9, whereas IR4819-77-3-2 and IR4829-89-2 received a score of 3.
- At Port Canning, India, where the nursery (1980) experienced submergence and soil stresses, the only entries rated good were: CR1009, CR1023, IR4829-89-2, IR8192-166-2-2-3, IR13646-55-1, and Mahsuri.
- In 1980, 3 days after seedlings were transplanted, the water level suddenly rose to 25 cm in the trial at Pusa, India, and within a month the level reached 75 cm. The entries rated good under these conditions were: BR51-282-8, IR8073-65-6-1, IR4568-86-1-3-2, IR9288-B-B-244-2, RP6-516-33-1-1, IR10198-66-2, IR10781-75-3-2, IR13365-253-3-2, IR13419-13-1, and IR13564-95-1.
- In the trial (1981) at Ranchi, India, drought occurred during the period of panicle initiation to flowering. The entries that were rated good for phenotypic acceptability were IR10781-143-2-3, IR13369-86-2-2, and IR4829-89-2.
- At Vytilla, India, throughout early growth, the crop in 1980 was under 30 cm water; entries that showed more than 50% survival were IR4829-89-2, IR9830-26-3-2, RD15, DW170, IR2039c-KN-7-2-5-3-1, C1117-2, KAU2019, CR149-3244-198, and IR9288-B-B-B5-2.

For all the years since establishment of the yield nurseries, IR13146-45-2-3 and BR4 have been among the highest yielders, and IR14632-2-3 for 3 of the years was a top yielder (Table 7).

Yield stability of entries in the 1983 IRRSWYN was determined by Seshu (1984) on the basis of data from 13 locations (4 from

Table 7. Entries (by year) in international rainfed rice shallow water yield nurseries (IRRSWYN 1981–84) that produced the highest yields.[a]

1981	1982	1983	1984
IR14632-2-3	IR8192-166-2-2	IR19431-72-2	BR11
IR14753-49-2	BR4	BR4	BR51-74-6/J1
BR4	IR46	IR13146-45-2-3	IR19083-22-2-2
IR13146-45-2-3	IR13146-45-2-3	RP975-109-2	BR4
IR10781-75-3-2	IR14632-2-3	IR10781-75-3-2	IR13146-45-2-3
IR4819-77-3-2	IR14753-49-2	IR14632-2-3	IR19431-72-2
IR46		IR4819-77-3-2	IR4829-89-2

[a]BR4 and IR13146-45-2-3 were among highest yielders for all 4 years, and IR14632-2-3 was one of the highest yielders in 3 of the 4 years.

Table 8. Stability indices for IRRSWYN trials of selected entries tested at 14 locations in 5 countries in 1983 and at 10 locations in 3 countries in 1984.

Entry	1983 Coefficient of variation (%)	1983 Stability index	1984 Coefficient of variation (%)	1984 Stability index
BR4	40.9	1.24	33.5	1.30
Cisadane	40.3	1.12	37.5	1.36
IR13146-45-2-3	32.9	0.91	23.9	0.89
IR19431-72-2	37.6	1.19	31.7	1.16
IR46	36.3	1.05	31.4	1.07
IR4819-77-3-2	43.4	1.31	34.2	1.24
IR4829-89-2	37.5	1.04	30.1	1.21
Mahsuri	33.7	0.78	24.9	0.71

Thailand, 3 from Nepal, 2 from Bangladesh, 2 from India, and 2 from the Philippines) where the coefficient of variation for yield was lower than 30% and where none of the 24 entries was missing in the trial. Variance among locations was lowest for IR2307-247-2-2-3 and BR10. IR2307-247-2-2-3 (b = 0.72), BR10 (b = 0.78), Mahsuri (b = 0.79), C1158-8 (b = 0.83), and IR18599-68-1 (b = 0.83) showed greater stability in terms of relative flatness of slope. The regression line of IR13146-45-2-3 (b = 0.91) also indicated good stability for yield across locations, and this breeding line was higher yielding than those of the other five varieties. IR19431-72-2 produced the overall highest yield in the trial but was less stable (b = 1.19) than BR10 and Mahsuri. From the point of view of relatively good performance at most locations, IR13146-45-2-3 appears promising, as it combines high-yield potential with great stability.

The consistency in performance of some of the entries is evident from the similarity of the stability indices derived from the 1983 and 1984 trials (Table 8).

Promising entries have been rated for agronomic characteristics, reactions to diseases and insects, and grain quality (Table 9).

CONCLUSIONS

The development of irrigation systems has resulted in increased rice yields for many formerly rainfed areas. Yet the potential increase of area under irrigation is limited. Development of irrigation and drainage systems is very costly ($3000–10 000/ha), and it is expensive to operate irrigation pumps. Herdt (1982) has predicted that, with the current trends in energy and rice prices, many farmers

Table 9. Traits of promising entries from nurseries of IRRI's program for rainfed lowland rice, 1978–83.[a]

Entry	Height (cm)	Days to flowering	Tolerance/resistance to:								Grain quality			
			D	S	BB	SB	BPH	GLH	SR	BL	Sh	Ch	Amylose	Gel
BR4	108	119	+	+	+						5	5	27	34
BR51-282-8	106	98		+	+						1	5	28	64
Cisadane	101	111				+					5	9	18	72
IR4819-77-3-2	104	106		+	+	+		+			5	9	27	32
IR4829-89-2	104	100	+	+		+		+			5	9	27	32
IR8192-166-2-2-3	100	113	+	+					+		1	1	18	32
IR10781-75-3-2	98	107	+	+			+	+			5	1	27	35
IR13146-45-2	108	107				+		+			1	1	27	100
IR13358-85-1-3	98	106									3	5	27	40
IR14632-2-3	101	106									1	1	28	90
IR14753-49-2	108	104							+		1	1	27	82
IR15853-89-7E-P3	94	99	+	+		+					1	5	28	35
IR19083-22-2-2	100	107		+	+	+	+	+			nd	nd	nd	nd
IR19431-72-2	99	107		+	+						5	1	28	73
IR21141-24-2	101	103							+	+	nd	nd	nd	nd
IR46	101	100					+		+		1	2	28	100
RP975-109-2	111	115							+		5	1	26	34
Mahsuri	124	112		+							5	5	26	34

[a]Abbreviations: D = drought, S = submergence, BB = bacterial blight, SB = sheath blight, SR = sheath rot, BL = blast, BPH = brown planthopper, GLH = green leafhopper, Sh = shape, Ch = chalkiness, nd = not determined; scoring as outlined earlier (IRRI 1980).

will not be able to pay for irrigation of their rice crop in the future. Rainfed lowland rice will thus be an important research priority for the foreseeable future.

Our program has been designed in the context of an international centre interacting with and coordinating efforts among a diverse group of national programs that are trying to solve similar problems. We realize that the breeding materials, techniques, and knowledge generated by this program may not have direct relevance to conditions in tropical Africa, considering the differences in environment and management practices. We have tried, however, to emphasize a promising approach to solving the problems involved in developing improved rices for difficult conditions. This approach involves a breeding program with strong input from scientists of various disciplines, a network of on-farm testing sites for varietal evaluation and management studies, and a mechanism for international evaluation and exchange of germ plasm targeted for specific environments. In our experience with rainfed lowland rice, the merits of a strong interdisciplinary and international approach have become obvious.

Although traditional varieties still predominate on much of the unfavoured rainfed lowlands, the attention being given to rainfed rice holds promise for substantial progress in the years ahead.

Cooperation between Africa, Asia and Latin America: the International Rice Testing Program

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Abstract *In 1984, the international organizations working with rice in Africa decided to integrate their efforts and to join forces with organizations in Asia and Latin America in the sharing and testing of germ plasm. Thus, the International Rice Testing Program was extended around the globe. Regional offices were established at the International Institute of Tropical Agriculture (Ibadan, Nigeria) and Centro Internacional de Agricultura Tropical (Cali, Colombia), with headquarters being maintained at the International Rice Research Institute in the Philippines. In 1985, IRTP-Africa distributed a total 185 sets of nurseries for testing under upland or lowland conditions. Varieties developed in Africa, particularly those for upland conditions, were among top yielders in Southeast and South Asia as well as in Africa. The major objective of the program is to identify suitable varieties for countries in Africa. Active participation and feedback from national programs are essential to the success of IRTP-Africa.*

Among the rice-growing countries in Africa south of the Sahara, Sierra Leone and Nigeria were the first to call for intensified efforts in rice research. In 1972, the West Africa Rice Development Association (WARDA) was launched to promote self-sufficiency in rice production and to assist 13 member countries. The headquarters were established in Monrovia, Liberia. WARDA organized a network of trials to identify superior varieties and appropriate techniques for crop protection and management. WARDA collected germ plasm from all over the world, including some from the International Rice Research Institute (IRRI) to test in West Africa.

The Institut de recherches agronomiques tropicales et des cultures vivrières (IRAT), the International Institute of Tropical Agriculture (IITA) with the assistance from the European Economic Community (EEC), and other organizations were also testing breeding materials to a limited extent in Africa. All these organizations were working essentially in isolation. Then, in April 1984, participants at an international rice workshop organized jointly by IITA and IRRI in Lusaka, Zambia, agreed to unify and integrate efforts in an African rice-testing program. A month later, representatives of WARDA, IITA, IRAT, and IRRI confirmed the structure of the program.

It would be part of a project launched at IRRI in 1975, with the assistance of a grant from the United Nations Development Programme: the International Rice Testing Program (IRTP) a systematic project for the collection and distribution of genetic materials. The directors general of CIAT (Centro Internacional de Agricultura Tropical), IITA, IRRI, and the executive secretary of WARDA signed a memorandum of understanding in June 1984, recognizing IRRI's global research obligation and mandate to coordinate IRTP. For effective regional focus, the IRTP has been organized into IRTP-Asia, IRTP-Africa, and IRTP-Latin America and Caribbean.

Advisory committees, headed by the directors general for the three international centres, steer IRTP's work in their institutions and the global coordinator is a member of all three committees. The international centres pool their resources to meet the expenses of the program and seek additional funding as and when necessary.

Any country can participate by requesting genetic materials for trials or submitting genetic material to be tested in other countries. The major objectives of IRTP are:

- To make the world's elite germ plasm available to rice scientists in the regions either for direct use as varieties or as parents for crosses in their breeding programs;
- To provide rice scientists with the opportunity to assess the performance of their own breeding materials over a wide range of climatic, cultural, soil, disease, and insect conditions within all the rice-growing regions of the world;
- To monitor and evaluate the genetic variation of pathogens and insects and identify sources of resistance to major diseases, insects, and other environmental stresses; and
- To promote interaction among rice scientists in various countries with special emphasis on Africa, Latin America, and the Caribbean.

Monitoring of the test crops is done by the national coordinators and other participating scientists; they are searching for varieties that yield well and have a wide adaptability. These varieties don't have to produce the highest yields in trials because over the years and under various agroecologic and other stresses, they will provide predictable yields.

IRTP-Africa is operated from IITA, Ibadan, with the IRRI liaison scientist and one member of IITA as the joint coordinators; it is supported by regional coordinators, one from WARDA for West Africa and one from IRRI for the East, Central, and Southern Africa (ECSA) region.

Varietal testing comprises three stages — preliminary screening, observational trials, and advanced trials. Although global IRTP at IRRI currently has 21 nurseries with germ plasm suited to different conditions, the program for Africa initially is limited to upland and irrigated ecologies and is to be extended to rainfed and hydromorphic ecologies and stress-screening nurseries. Also the program may include screening for tolerance to cold, iron toxicity, and acidic soils. Nurseries for rice yellow mottle virus, blast, bacterial leaf blight, *Diopsis*, and gall midge will also be sought. IRTP-Africa staff will multiply seeds, prepare packages of material for testing and distribute them. The packages will contain a standard fieldbook with data sheets for recording and reporting data about the performance of the crops. The sheets will be returned to headquarters for analysis and publication. If funds are available, 8–10 participants will visit the sites to observe the genotype-environment interaction of the different entries and to identify constraints to rice production in different locations. Their observations will be published in the IRTP-Africa report.

The African program is now in place; nurseries obtained from IRRI have been subjected to plant quarantine according to the regulations of the Nigerian government. They are evaluated and the superior performers in Africa along with those from IITA, WARDA, and the African national programs are composed as nurseries for IRTP-Africa. The fieldbooks have been assembled and printed at IITA and distributed along with the materials for trials. The nurseries composed and distributed in 1985 for testing in upland conditions were:

- First African upland rice preliminary screening set (AURPSS-1985), 12 sets;
- First African upland rice observational nursery (AURON-1985), 34 sets; and
- First African upland rice advanced variety trial (AURAVT-1985), 41 sets.

For the lowlands, the nurseries were:

- First African irrigated rice preliminary screening set (AIRPSS-1985), 13 sets;
- First African irrigated rice observational nursery (AIRON-1985), 40 sets; and

- First African irrigated rice advanced variety trial (AIRAVT-1985), 45 sets.

The countries that received nurseries were Ghana, Liberia, Nigeria, and Senegal in West Africa; Burundi, Kenya, Madagascar (selected varieties), and Tanzania in East Africa; Cameroon, Congo, and Zaire in Central Africa; Malawi, Zambia, and Zimbabwe in Southern Africa. Nurseries were also distributed to Brazil, Colombia, and Peru. In addition, WARDA received the nurseries in bulk for distribution to 16 member countries.

ACHIEVEMENTS AND FUTURE PROSPECTS

With the diverse genetic materials now available through IRTP-Africa, breeders can efficiently select varieties that are suited to their conditions. They should be able to improve on their existing elite lines (at least 26 varieties were selected from the global IRTP nurseries by 13 subsaharan countries over the last decade).

In 1985, the National Cereals Research Institute (NCRI), Nigeria, reported that IRTP materials of short and medium duration yielded 4-6 t/ha under lowland conditions. The yield potential of these elite lines may be as high as 10 t/ha. Some of the elite lines were vulnerable to stresses and yielded as little as 0.1 t/ha under upland conditions. IRAT 112 and IRAT 133 outyielded all other entries, with mean yields of 4.3 t/ha and 4.9 t/ha respectively in upland trials.

In acidic upland soils, Azucena, ITA 116, ITA 142, IRAT 104, and ITA 235 were rated good for phenotypic acceptability. Among them, ITA 235 was also rated good for drought tolerance and recovery from drought.

In 1983, ITA 212 was rated among the best entries from the irrigated, medium-duration varieties, based on overall performance in 30 trials all over the world.

For comparison in 1984, under upland conditions in India, IRAT lines 109, 110, 134, and 142 outyielded all other entries. Their yields were 2.7, 2.8, 2.8, and 3.2 t/ha. Similarly, IRAT 112 and 142 were ranked number one in Southeast Asia and South Asia respectively, while IRAT lines 109, 134, and 142 were among the first five top yielders in Burma, Thailand, and India. These lines and others that performed well in the trials were developed in Africa and would not have been discovered outside a limited area if it were not for IRTP.

Within a few months of its inception, IRTP-Africa has achieved considerable success and recognition. For instance, a total 185 sets for six types of nurseries comprising several hundred entries were sent to 29 countries in 1985. Also during 1985, 15 rice scientists from several national programs and from IITA headquarters were involved in monitoring tours to key locations in four rice-growing countries to assess the performance of test entries in different trials and to interact with other researchers. This is a major achievement since rice scientists in many countries are confined to their own stations because of lack of logistic and other supports.

As a result of such trials and their evaluation, several promising entries have been identified for large-scale cultivation. The monitoring tour participants in the upland trials in Cameroon, Côte d'ivoire, and Liberia identified nine elite varieties:

- AURON — CRM-A1-2418, IR6023-10-1-1, IRAT 170, ITA 132, and ITA 187; and
- AURAVT — IRAT 104, ISA 6, ITA 235, and ITA 257.

Thus, IRTP-Africa offers developing countries in Africa, improved rice germ plasm for evaluation and use in their national programs.

Such free exchange of breeding materials is a tribute to the spirit of mutual cooperation among rice scientists irrespective of sociopolitical differences. Through such free and voluntary exchange of breeding materials, breeders have made a significant contribution to the rice production of the world.

Because of the different growing season in East Africa, the 1985 IRTP-Africa nurseries there were to be conducted from October 1985 to March 1986 at which time a meeting in Tanzania was planned to evaluate and redefine the strategies and priorities for IRTP-Africa. Also more nurseries for different target conditions are to be constituted in future.

DISCUSSION SUMMARY

What kind of land preparation is required for direct seeding?
Direct seeding requires good water control and leveling. Otherwise, transplant.

What is the best plant type for rainfed lowland rice?
For rainfed cultivation, farmers prefer varieties of intermediate height as they compete with weeds better than do semidwarfs and they tolerate drought stress and flooding. A yield of 4-5 t/ha is considered very good.

Are breeders aware of the characteristics of sites where varietal trials are conducted?
IRRI is starting to monitor hydrologic and soil characteristics at its trial sites and is not sure yet how well the sites represent the large areas of rainfed rice.

Because of competition for labour with upland crops in Africa, the farmers transplant their lowland rice late, with consequent losses in yield. Can this problem be tackled through breeding?

When transplanting is delayed, one way to minimize losses is to avoid using very early maturing varieties, although agronomists are currently evaluating early varieties for adaptation to late transplanting.

Birds are a serious rice pest in Africa. Can one breed for bird resistance?
Some plant characteristics such as upright flag leaf and awness limit predation by birds and can be achieved through breeding, but probably a more effective method is to control the birds.

As resources and personnel are limited in most national programs in subsaharan Africa, how can they become involved in IRTP-Africa?
Government and donor agencies should seek ways to strengthen the position of weak national programs, and IITA, IRRI, and WARDA could offer training and coordination.

CROP PROTECTION AND NUTRITION

Diseases and insect pests of wetland rice in tropical Africa

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Abstract *In Africa, as elsewhere in the world, blast, caused by* Pyricularia oryzae, *is the most prevalent disease of rice, particularly damaging in the uplands but also affecting lowland rice. Rice yellow mottle virus (RYMV) and the major insect pests are specific to Africa. Efforts at IITA to control the damage by pests and diseases focus on identifying sources of resistance and incorporating them into high-yielding varieties. The approach has proved successful in the development of high-yielding blast- and drought-resistant varieties. Also sources have been identified for resistance to RYMV, stalk-eyed fly, pink stem borer, white stem borer, striped stem borer, and gall midge; some of these are being used in the breeding program.*

The adverse environmental conditions of African wetlands, including periods of drought and fluctuating water table, determine the type and intensity of rice diseases and insect pests. Unlike distinctly dry or flooded conditions, the wetlands form a complex ecology for host-pathogen-pest interactions. Among diseases of wetland rice (Table 1), blast, caused by *Pyricularia oryzae*, is probably the most common worldwide and the most yield depressing.

In contrast, rice yellow mottle virus (RYMV) and insects like the stalk-eyed fly (*Diopsis macrophthalma*) and gall midge (*Orseolia oryzivora*) are mainly restricted to the lowlands and are distinctly specific to Africa.

Although the total losses caused by fungal, viral, and bacterial pathogens as well as major species of insects are not known, they definitely discourage rice production on the continent. Thus, the major strategy of IITA has been to screen large quantities of germ plasm to identify sources of resistance to the stresses.

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Table 1. Major diseases of rice in the wetlands of tropical Africa.

Disease	Ecology	Severity
Blast		
(Pyricularia oryzae)	Dryland	Severe
	Hydromorphic	Moderate
	Lowland	Low
Glume discoloration		
(fungal complex)	Dryland	Severe
	Hydromorphic	Moderate
	Lowland	Low
Rice yellow mottle virus	Dryland	Not reported
	Hydromorphic	Moderate
	Lowland	Severe

MAJOR DISEASES

Under dry or upland rainfed conditions, leaf and neck blast of rice caused by *P. oryzae* can be serious (Table 1). Alternate drying and wetting of the soil with an abundance of dew can increase disease severity, especially if the soil is porous and is freely drained, with a low moisture-holding capacity.

Traditional rice varieties in Africa have shown excellent resistance to leaf and neck blast. Grown in the blast-prone uplands of Africa, they exhibit "durable resistance" as defined by Johnson (1981). Varieties like OS 6, Moroberekan, LAC 23, 63-83, Dourade Precose, Iguape Cateto, and IAC 25 from Africa (Table 2) and Brazil have been used extensively in IITA's breeding program with high-yielding Asian dwarfs. The progenies have been rigorously selected for drought and blast resistance (and for deep and thick root systems).

Table 2. African traditional varieties used in crosses with Asian dwarfs and the level of blast resistance.

Variety	Total	Parents (% used) Male	Parents (% used) Female	Level of blast resistance[a]
OS 6	33	13.5	19.5	2–4
Moroberekan	22	10.0	12.0	0–4
LAC 23	34	18.0	16.0	0–4
Dourade Precose	4	1.0	3.0	0–4
IAC 25	3	1.5	1.5	0–4

[a]Measured by range of score, based on Standard Evaluation System for Rice (IRRI 1980b) where 0 is highly resistant and 9 highly susceptible.

From results of such a breeding program involving repeated testing and evaluation of progenies, high-yielding blast- and drought-resistant entries have been identified (Fig. 1). Entries with resistance to leaf blast generally show resistance to neck blast.

Several upland and lowland entries with high levels of leaf and neck blast resistance suited to wetland conditions with a fluctuating water table are available for cultivation. The upland entries include ITA 117, ITA 120, ITA 257, TOx 891-212-2-102-101-4, TOx 936-87-10-3-101, TOx 936-397-9-1-2, TOx 955-202-2-101, and TOx 1010-24-15-3; the lowland entries include ITA 121, ITA 212, ITA 306, ITA 230, IR7167-33-2-3, ADNY 11, ITA 233, and several CIAT lines.

GRAIN DISCOLORATION

Like blast, grain discoloration is serious in both the uplands and the lowlands, but more so in the uplands. A fungal complex dominated by species of the genera *Sarocladium* and *Curvularia* is regarded as a major factor in this disease. The disease is aggravated by prolonged dew, rain, low light intensity, and unfavourable soil conditions. The discoloration may be superficial — restricted to the husk — or it may extend to the kernel. In extreme cases 100% sterility is induced.

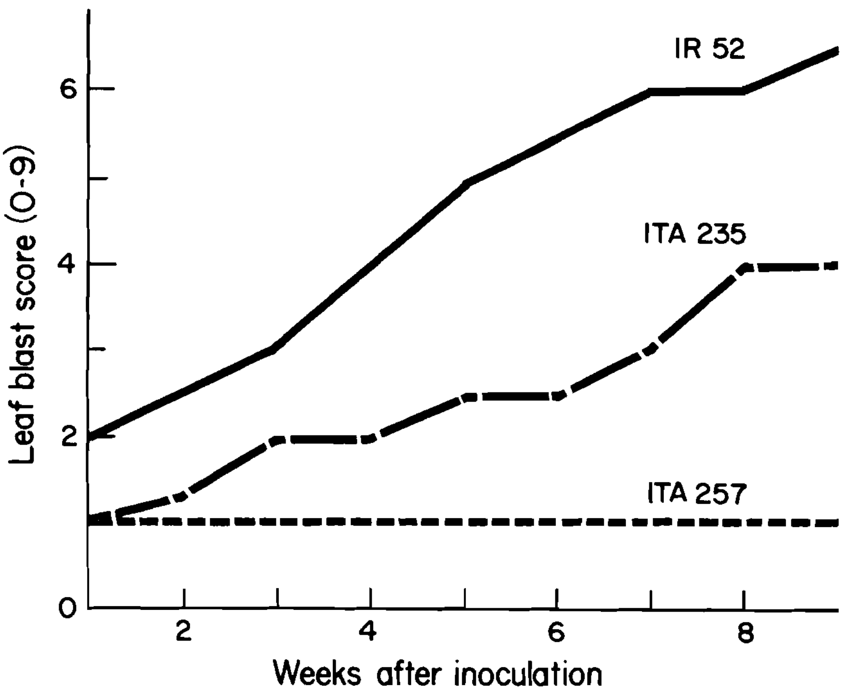

Fig. 1. Scores for three varieties of rice, from 0 to 8 weeks after inoculation.

In the Ndop Plain of Cameroon (elevation 1100 m) varieties that flower in September invariably have discoloured grains because of infection by *Sarocladium* sp. (sheath rot). One way to solve this problem is to advance the planting date. Also, varieties like IR7167-33-2-3 and B2161-C-MR-57-1-3-1 have shown considerable resistance to this problem and have good panicle exsertion. In the uplands LAC 23 is a good parent as a source for clean grains.

Several minor diseases also affect rice in the wetlands — for example, sheath blight (caused by *Thanetophorus cucumeris*), bacterial leaf blight (*Xanthomonas campestris* p.v. *oryzae*), leaf scald (*Rhyncosporium oryzae*), and false smut (*Ustilaginoidea virens*). They should be given some attention in screening and breeding programs so that they do not escalate into major threats.

VIRUSES

The Africa-specific rice yellow mottle disease, first reported in 1966 from Otonglo near Lake Victoria in Kenya (Bakker 1970, 1971, 1974) has been subsequently reported from Sierra Leone (Raymundo and Buddenhagen 1976), Côte d'ivoire (Fauquet and Thouvenel 1977), Nigeria (Rossel et al. 1982a,b), Niger, Burkina Faso, and Mali (John et al. 1984). Rice yellow mottle virus, therefore, occurs in both East and West Africa.

The characteristic symptoms are yellowing, mottling, necrosis, stunted growth, partial emergence of panicles, and spikelet sterility. Yellowing, the initial symptom, is noticed about 10–15 days after inoculation. The youngest leaves show distinct mottling. In some varieties the most characteristic symptom is oranging of the older leaves. The symptoms caused by iron deficiency in the uplands can be mistaken for RYMV infection; however, in the case of iron deficiency, mottling is not present.

The severity of symptoms depends upon the variety and the age of plants at the time of infection. If the infection occurs in the early stages of growth, fewer tillers are produced than if the infection occurs later. In severe cases, the infected plants die prematurely.

In recent studies at IITA using enzyme-linked immunosorbent assay (ELISA), RYMV has been detected in various parts of infected plants (Fig. 2). In general, the older parts of the plant (leaves, outer leaf sheaths) contain less virus than the young parts, and the floral parts and the stem bearing the panicle contain abundant virus. This finding has considerable epidemiologic significance. Infected stubbles freshly plowed into the soil can serve as an inoculum for a newly transplanted crop, mostly with damaged roots. The possibility of large-scale field infections via this route is being studied at IITA.

Exotic lowland varieties that have been tested are generally highly susceptible to RYMV, whereas traditional African upland varieties are tolerant (Raymundo and Konteh 1980; Okioma and

Sarkarung 1983). Similarly, the indigenous African *Oryza* species like *O. glaberrima*, *O. longistaminata*, and *O. barthii* are resistant (Attere and Fatokun 1983; Rossel 1984), although naturally infected *O. longistaminata* were detected in Mali and Niger (John et al. 1984). This was the first report of a natural host for RYMV. Subsequently, Rossel (1984) noticed that certain collections of *O. longistaminata* were susceptible while others were resistant.

Yellow mottle can be transmitted to healthy plants by sap inoculation. Insects with chewing mouth parts, mainly chrysomelid beetles, also transmit the virus. In Nigeria, *Chaetocnema* spp. and

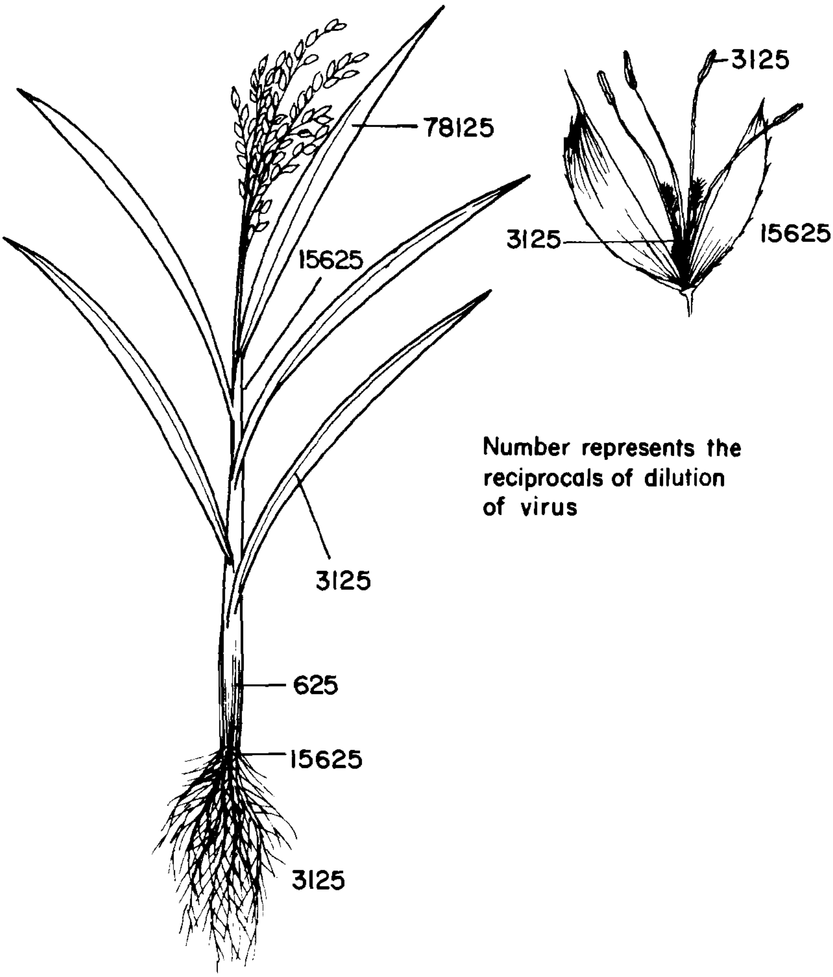

Fig. 2. Distribution of RYMV in an infected plant.

Aulacophora africana have been shown to be vectors of RYMV (G. Thottappilly and M.S. Alam, unpublished). No seed transmission was observed in experiments with more than 5000 seeds from infected plants.

RYMV is a spherical virus with a particle diameter of about 30 nm. Recently at IITA the virus was purified and an antiserum having a titer of 1/4096 in agar gel-diffusion tests was prepared. Various serological techniques, including ELISA, have been successfully applied with this serum, which has been used to detect suspected RYMV infections from greenhouse and field samples. The antiserum has also been used for surveys in other countries (John et al. 1984).

Traditional African upland varieties such as OS 6, LAC 23, and Moroberekan that are resistant or tolerant to RYMV are being used in the breeding program at IITA to develop high-yielding varieties with adequate resistance to RYMV.

INSECT PESTS

Like diseases in Africa, many insect species causing damage to wetland rice are indigenous, and about 15 species of insects are considered to be major pests of the crop (Table 3, Fig. 3).

The insect pests of wetland rice in Africa are classified into four groups: stem borers, leaf feeders, grain suckers, and stem and leaf suckers. Of these, the stem borers generally cause the most damage.

Lepidopterous stem borers and two dipteran stem borers (stalk-eyed fly and gall midge) are important in Africa. Because of their feeding habit and the late appearance of external injury to the plant, they usually remain undetected for some time. The lepidopterous stem borers and the stalk-eyed fly are more widespread and are observed more frequently than gall midge.

Pyralidae such as *Chilo, Maliarpha, Scirpophaga,* and *Adelpherupa* and Noctuidae such as *Sesamia* are the lepidopterous stem borers reported in Africa (Akinsola and Agyen-Sampong 1982). Among these the white stem borer (*Maliarpha separatella*), the striped stem borer (*Chilo* spp.), and the pink stem borer (*Sesamia* spp.) are common. The white stem borer is predominant in all rice ecosystems in Africa. Unlike other stem borers, it does not produce the usual symptoms of "dead heart" or "white head," and it is host-specific. In studies at IITA (1985), economic yield loss in irrigated rice was 11.7% when the infestation level of the white stem borer was 53.7%. During adverse environmental conditions, larvae of white stem borer can undergo diapause in rice stubbles.

Several species of *Chilo* are reported as pests of wetland rice in Africa, with *C. zacconius, C. diffusilineus,* and *C. partellus* being

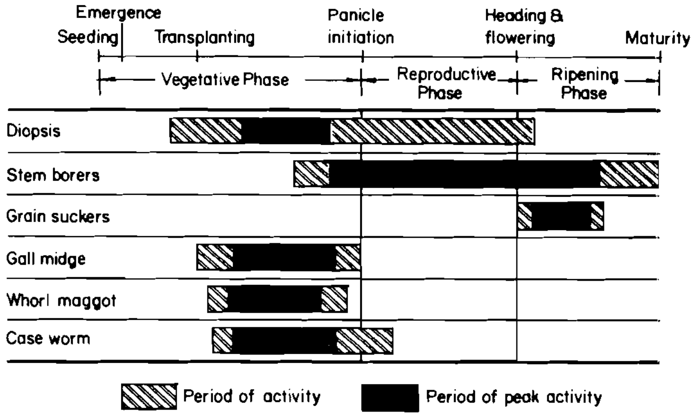

Fig. 3. Major insect pests of lowland rice in Nigeria and their relation to growth stages of the plant (Alam et al. 1984).

Table 3. Prevalence of major insect pests of rice in three climatic zones of Africa (Agyen-Sampong 1982; Alam et al. 1984).

		Presence in climatic zone[a]		
Insect	Scientific name	Humid tropics	Guinea savanna	Sudan savanna
Stem borer				
White	*Maliarpha separatella*	+++	+++	+
Striped	*Chilo* spp.	+++	+++	+++
Pink	*Sesamia* spp.	+++	+++	+++
Stalk-eyed fly	*Diopsis macrophthalma*	+++	+++	+++
Army worm	*Spodoptera* sp.	+	+	+
Grain-sucking bugs	*Aspavia* sp.,	+++	+++	+
	Stenocoris claviformis	+++	+++ +	
Case worm	*Nymphula depunctalis*	+++	+++	+
Gall midge	*Orseolia oryzivora*	—	+++	—
Whorl maggot	*Hydrellia* sp.	+++	+	—
Hispa	*Trichisa* sp.,	+	+	—
	Dicladispa sp.	+	+	—
Leaf folder	*Marasmia trapezalis*	+	+	—

[a]+++ = abundant; + = present; — = not reported.

common. *Chilo* species are polyphagous and are widely distributed in all climatic zones. Pink stem borer is the most polyphagous insect among borers. Two major species, *S. calamistis* and *S. botanephaga*, are present in Africa and are more abundant in humid tropical zones than in the guinea and sudan savannas.

Many species of *Diopsis* are found in Africa but predominant is *D. macrophthalma* (*D. thoracica*). It is more serious in irrigated and lowland rainfed rice than in upland rice. It generally attacks the rice plant at the early tillering stage while lepidopterous stem borers attack at a later stage (Fig. 4). Peak infestation usually occurs between 20 and 40 days after the seedlings are transplanted, and "dead heart" symptoms are exhibited.

Gall midge (*O. oryzivora*) is well established in the guinea and sudan savannas, being found in Guinea-Bissau, Senegal, Mali, Burkina Faso, Côte d'ivoire, Nigeria, Cameroon, Sudan, Zambia, and Malawi (Alam et al. 1985). It is morphologically distinct from the Asian species and is one of the most serious and widespread pests of Burkina Faso in irrigated, rainfed, and lowland rice. Feeding by the maggot stimulates the leaf sheath to grow a gall (silvershoot). Tillers having galls bear no panicles.

Among the leaf feeders, case worm, whorl maggot, hispa, army worm, and leaf folder are known to be present on wetland rice in

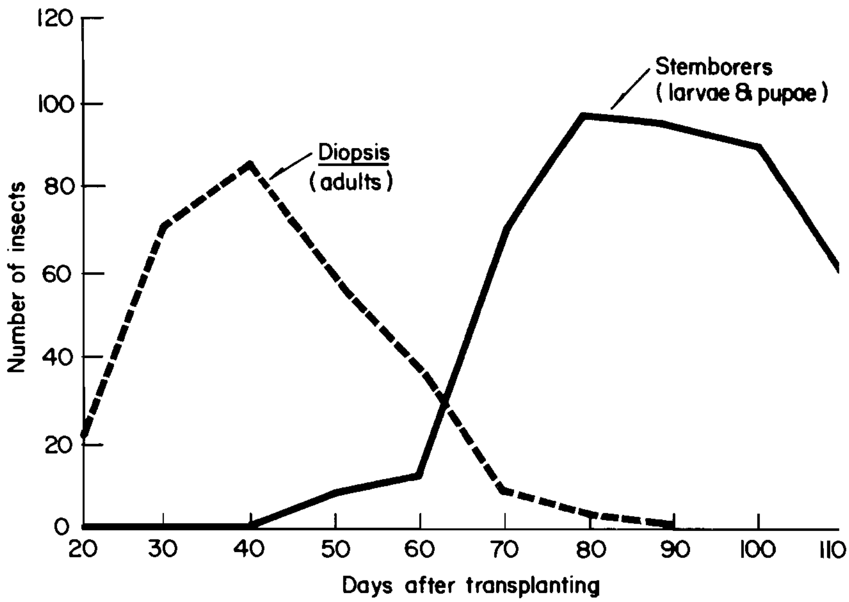

Fig. 4. Relationship between the phenologic characteristics of irrigated rice (ITA 212) and field infestation by lepidopterous stem borers and Diopsis *spp. (IITA 1983).*

Table 4. Sources of resistance to major insect pests in Africa (IITA 1975–84; Soto and Siddiqi 1976).

Insect	Source of resistance[a]
Striped stem borer	TOs 2513, Taitung 16, PR403, ITA 6-20-1-BP1, IR503-1-91-3-2-1, PR325, H8, Ratina, Malagkit sung song, SML 81B
Gall midge	BW 100, PTB 18, PTB 21, PTB 10, OB 677, RJP 1831-4-5, Cisadane, Eswarakora
Stalk-eyed fly	IR579-160, Iguape Cateto, Leuang 28-1-64, DNJ 171, CTG 680, IR589-53-2, E.L. Golpher, IR1561-38-6-5, Huangesengoo, TD 10A, Magoti, TOg 6324, TOg 6367, TOg 5560, TOg 6481, TOg 6399, TOg 6390, TOg 6392, ITA 121*, DJ 12-539-2*, HPU 741*
Pink stem borer	W 1263, Taitung 16, SML 81B, DNJ 171, DNJ 146, Sikasso
White stem borer	ITA 6-4-2, IR1168-76*, IR1561-38-6-5*, ITA 7-7-2*, TKM-6*

[a] * = moderately resistant.

Africa. They are widely distributed like lepidopterous and dipteran borers, but in some countries they are considered as serious pests, e.g., case worm in Liberia and rice hispa in the Republic of Malagasy.

There are at least 15 species of grain suckers that have been reported in Africa. Of these, *Aspavia armigera, A. acuminata,* and *Stenocoris* spp. are important.

Of the stem- and leaf-sucking insect pests, green leafhopper (*Nephotettix* spp.) and brown planthopper (*Nilaparvata maeander*) are considered as potential pests because they are serious in Asia and Latin America.

The strategy for insect control at IITA has been mainly through resistance breeding. The techniques for varietal screening against major insect pests have been developed, and more than 6000 varieties/lines have been evaluated for resistance to stalk-eyed fly, pink stem borer, white stem borer, striped stem borer, and gall midge. Several cultivars have been identified as sources of resistance to these insects (Table 4).

A breeding program for developing resistance to stalk-eyed fly and gall midge has already been initiated, and the progenies are now in the F_3 generation. Also, agronomic practices have shown some potential for reducing populations of lepidopterous stem borers, stalk-eyed fly, and whorl maggot. For example, results of tests with whorl maggot showed that plants spaced 10 × 25 cm apart and fertilized at a rate of 120 kg N/ha had higher than normal rates of infestation. The stalk-eyed fly infestation was similar to that of whorl maggot, but the infestation of lepidopterous borers decreased as plant spacing decreased (IITA 1985).

Flood-mediated resistance to the rice blast disease

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Abstract *Research was conducted to determine the nature of observed differences in rice plants' resistance to blast (caused by* Pyricularia oryzae *Cav.) under different systems of water management. The development of blast was monitored on two varieties (M-201 and Brazos) of rice in plots maintained under upland, flooded (paddy), upland changed to flooded, and flooded changed to upland conditions. M-201 had no known resistance to the race of* P. oryzae *used, and Brazos had partial resistance. Microclimatic factors were monitored continuously by microcomputer. Leaves were collected and sampled for content of 13 nutrients. Lesion size and number and spore production were also monitored. There were highly significant differences in disease development on plants in upland and flooded plots: final disease severity for the varieties M-201 and Brazos in upland plots was 67% and 48%, respectively, compared with less than 0.1% for both cultivars in flooded plots. Flooding the upland plots of Brazos greatly decreased the rate of blast development and final disease levels, whereas it had little effect on blast in M-201. No change in disease progress was observed when flooded plots were drained and changed to upland conditions. Lesion size did not differ between flooded and upland conditions, and the difference in disease development was a reflection of reduced numbers of successful infections. This finding suggests that physiologic differences occur in plants grown under upland and flooded conditions, and these differences affect defense mechanisms associated with infection progress. Yields were significantly affected by the differences in blast. For the 13 elements evaluated from leaf samples, no significant differences were recorded in nutrient levels of phosphorus, potassium, calcium, iron,*

Flooded and upland conditions were simulated by the use of levees for water control; the microclimate was monitored by microcomputer.

zinc, aluminum, or copper between plants grown under upland and flooded conditions. Nitrogen, sulfur, and magnesium contents were higher in plants from upland conditions, and silica content of leaves was significantly greater in flooded plots. Early in the monitoring period sodium content in leaf samples from flooded plots was four times that found in leaves from upland plots; it rapidly dropped in flooded plots and remained constant in upland conditions. Of all the elements, manganese content most closely reflected differences in disease development in the two varieties under different water-management practices.

The principal disease of rice, because of its wide distribution and destructiveness, is blast caused by *Pyricularia oryzae* Cav. (Ou 1972). Rice seedlings or plants at the tillering stage are often completely killed by the disease, and yield losses attributed to the disease are about 25% of the total losses caused by pests in Asia.

Leaf blast symptoms are reported to be more severe in dry soil or in upland rice than in flooded conditions or in paddy rice (Hemmi and Abe 1932; Suzuki 1934; Ou 1972; IRRI 1974). In 1934 Suzuki reported that plants in soils with low levels of moisture exhibited lower levels of leaf silicification and higher uptake of nitrogen than did plants growing in wet soils and proposed that resistance/

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Toward the end of the season, the differences in blast were apparent, a reflection of fewer successful infections rather than less severe disease in flooded plots.

susceptibility to leaf blast was a reflection of these differences. Since then, the subject has not been extensively studied, although differences in air temperature, leaf-wetness duration, and relative humidity have been suggested as reasons for the phenomenon.

As the causes of the differences in resistance still remain unknown, our research was carried out to examine them. Preliminary reports have been published elsewhere (Kim et al. 1985, in press a,b). The experiments were conducted during the 1984 season.

In a field test, plots were established with four main treatments in water management; two blast-susceptible rice varieties (Brazos and M-201) were the subtreatments in a split-plot design. The main plots were surrounded by levees so they could be watered and drained independently.

One treatment had a continuous flood from the 4–5 leaf stage to maturity. An upland treatment was not flooded but was watered by rain or irrigation as needed to maintain the rice. The other two treatments were changed from upland to flooded or flooded to upland when the plants reached the first joint-elongation stage of growth. Split plots had dimensions of 4.5 × 6 m. All treatments were replicated three times.

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A weather station in the field incorporated a CR-21 micrologger to record temperatures, leaf wetness, etc. The data indicated that the microclimate in flooded plots favours blast.

The source of inoculum consisted of one plant infested with race IH-1 of *P. oryzae*; it was introduced into each subplot.

We recorded disease progress every 3-7 days by counting or estimating the number of lesions per leaf on plants that had been randomly selected and marked at the beginning of the experiment.

There were major differences in disease development between upland and flooded plots. Disease progressed rapidly in upland plots but was greatly reduced in flooded plots regardless of variety. Final disease severity in upland plots was about 67% for M-201 and 48% for Brazos, whereas in flooded plots the corresponding figures for both varieties were less than 0.1%. Apparent infection rates of *P. oryzae* on M-201 and Brazos in upland plots averaged 0.161 and 0.131 unit/day. When upland plots were flooded at an early stage of the epidemic, further development of blast on Brazos was greatly decreased with a final disease level of 17%. In contrast, disease development in M-201 slowed only for a short time, reaching a final level of 51%. In flooded plots that were drained, the disease remained at the low levels typical of flooded conditions throughout the rest of the season.

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PHYSICAL ENVIRONMENT

Weather stations were placed in adjacent upland and flooded plots. Precalibrated sensors of temperature, leaf wetness, relative humidity, and soil moisture were extended from a CR-21 Micrologger in each weather station, which was programmed to collect data every 8 min and to store the information on a cassette recorder throughout the growing season.

Differences in daily minimum, maximum, and mean air temperatures between upland and flooded plots were all within 1°C. Daily minimum temperatures were not significantly different between the two conditions, whereas daily maximum temperatures were always significantly higher in upland plots, with an average difference of 0.65°C.

In flooded plots, leaves were wet an average 0.7 h longer than in upland plots, and relative humidity was always significantly ($P < 0.05$) higher under flooded conditions. For example, daily hours of high humidity (> 90%) averaged 12.3 h and 18.9 h. For this reason, we concluded that the microclimates in flooded plots favoured blast development at least as much as and probably more than those in upland plots.

NUMBER OF LESIONS AND LESION SIZE

A total 232 plants were sampled nine times at 3–7-day intervals from upland and flooded plots to determine the number of lesions and lesion size. A total 115–700 lesions were measured at each sampling time.

The number of lesions per tiller was greatly reduced in flooded plots: for Brazos and M-201 the number was 24.8 and 26.4, respectively, in upland plots and 1.8 and 4.4 in flooded plots. Lesion size was slightly, but not significantly, reduced with both varieties on leaves from flooded plots.

To monitor new infections in each treatment, we examined newly developing lesions on the upper two leaves on 10 tillers per subplot at 4–5-day intervals beginning 32 days after inoculation.

Development of new infections was greatly reduced in flooded plots for both varieties. Usually fewer than one new lesion per tiller was observed in flooded plots. In upland plots the number of new infections per tiller averaged 4.8–7.5 on M-201 and 3.7–9.0 on Brazos, depending on the day of examination. Development of new infections gradually decreased on Brazos, whereas M-201 continuously developed new lesions. In upland plots that were flooded, the rate of development of new infections on Brazos significantly decreased and became the same as that in flooded plots.

In contrast, development of new infections on M-201 was not significantly affected after upland plots were flooded. There was no apparent increase in number of new infections when flooded plots of either variety were drained.

PRODUCTION OF CONIDIA

Using a small flask vacuum, we collected conidia from the surface of 30 randomly chosen lesions per subplot. Spore collections were made six times during the season.

Production of conidia was significantly reduced in flooded plots. Mean conidia per lesion on M-201 from upland and flooded plots averaged 10 800 and 4700, respectively. Lesions on Brazos in upland plots also produced 2–4 times as many conidia as did those in flooded plots.

PANICLE BLAST

Development of panicle blast was determined twice near the end of the growing season. The numbers of rotten-neck lesions and infections on individual panicle branches were recorded on 100 tillers per subplot.

There were no significant differences in panicle blast infection on M-201 in upland and flooded plots. More than 90% of the panicles examined were affected by rotten-neck blast regardless of water management during the growing season. Panicle blast on Brazos was significantly reduced in flooded plots (52%), compared with upland plots (76%). In plots converted from upland to flooded conditions and from flooded to upland conditions, rotten-neck development on Brazos was similar to that in flooded plots.

YIELD

Yields of upland plots were less than 1/10 of those from flooded plots for both varieties. Average yield of M-201 in flooded and upland plots was 2787 kg/ha and 205 kg/ha, respectively, whereas Brazos in flooded and upland plots yielded an average 4214 kg/ha and 363 kg/ha.

Because of severe rotten-neck infections in both varieties, especially in M-201, yields of the flooded plots were also reduced. Yields of Brazos from upland plots converted to flooded conditions were significantly higher (2526 kg/ha) than those from upland plots. In flooded plots that were drained, M-201 and Brazos yielded 1792 kg/ha and 3062 kg/ha, respectively.

PHYSIOLOGIC CHANGES

Using the Kjeldahl method for total nitrogen, the filtering method for silica, and the atomic absorption spectrophotometric evaluation for aluminum, calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, sulfur, and zinc, we analyzed 159 leaf samples collected sequentially at 3-7-day intervals from upland and flooded plots.

Contents of total nitrogen for both varieties differed greatly between upland and flooded conditions, with Brazos and M-201 averaging 29% and 35% more nitrogen in upland plots than in flooded plots. Percent nitrogen content, based on dry weight of leaf tissue, gradually decreased as the season progressed regardless of variety or treatment. The decrease in nitrogen content was more rapid in flooded plots. Varietal differences for nitrogen were not significant, the percentage in leaves declining from 5.6 to 3.0 for Brazos and 5.3 to 2.6 for M-201 in upland plots and from 3.5 to 2.4 and 4.2 to 2.1 in flooded plots. The magnitude of difference in nitrogen content between upland and flooded plots was much greater in the early stages of growth.

This period was also critical for development of the epidemic. Leaf samples collected from upland plots during this period had at least 50% more nitrogen than leaves from flooded plots. When plots were converted from upland to flooded conditions or flooded to upland conditions, no major changes in nitrogen content of tissues were observed in either variety.

Phosphorus in leaf tissues was generally higher under flooded conditions. Mean values in leaf samples from upland and flooded plots were 1972 ppm and 2277 ppm for M-201 and 1976 ppm and 2023 ppm for Brazos, respectively. These differences were only significant for M-201. The contents did not change significantly as plants aged.

Potassium in leaves did not vary significantly between upland and flooded plots with either variety, being 21.3 mg and 21.8 mg for M-201 and 23.2 mg and 21.5 mg for Brazos, respectively.

However, leaf samples from flooded plots contained significantly more silica than those from upland plots with both varieties; on a dry-weight basis, the silica gradually increased from 12.6% to 19.4% in flooded plots as plants grew. In upland plots, it remained at about 10-11% throughout the season for both varieties.

For this reason the difference in silica content of leaves from flooded and upland plots became significantly greater as the season advanced. Flooded plots averaged 52% and 32% more silica than upland plots in M-201 and Brazos, respectively. When upland plots were flooded, the amount of silica in leaf tissues of both varieties was greatly increased. In Brazos, it reached the same level as that in leaves from flooded plots; in M-201, however, it remained far less than in the flooded treatment. When flooded plots were drained, the silica content of leaves was not appreciably changed in Brazos but it became significantly reduced in leaves of M-201.

Calcium content did not differ significantly in leaves from plants in upland and flooded plots with either variety; in leaf tissues from upland and flooded plots, it averaged 2765 ppm and 2828 ppm for M-201 and 2862 ppm and 2749 ppm for Brazos. Leaves of the two cultivars contained about the same amount of calcium throughout the season.

Leaf samples of M-201 and Brazos from upland plots contained 32% and 26% more sulfur, respectively, than did leaves from flooded plots. Sulfur in leaf tissues of M-201 was 2343 ppm and 1771 ppm for upland and flooded plots, somewhat higher than Brazos for both treatments.

Sulfur in leaf tissues of both varieties gradually decreased as plants became older regardless of treatment. When upland plots were flooded, sulfur generally increased in the leaves of both cultivars. Conversely, it decreased when flooded plots were drained.

Magnesium was significantly increased in leaf samples from upland plots: 48% and 26% respectively for M-201 and Brazos. The difference increased with time and did not vary significantly between varieties as the season progressed; it decreased in both varieties when upland plots were flooded but did not change after flooded plots were drained.

Of the 13 nutritional elements examined in leaves, manganese was the element that showed the greatest differences between upland and flooded treatments. Leaf tissue of both varieties from flooded plots had 2-3 times as much manganese as that of upland plots: 976 ppm and 409 ppm for M-201 and 1135 ppm and 354 ppm for Brazos. Manganese content did not vary significantly between varieties and did not change in M-201 when upland plots were flooded or when flooded plots were drained. With Brazos, manganese increased significantly after upland plots were flooded but was not significantly affected when flooded plots were drained.

Sodium content in the leaves, like manganese content, differed greatly between upland and flooded plots. The differences were particularly great at early stages of growth. Leaf samples from flooded plots contained four times as much sodium as those from upland plots with both cultivars, at 8 days after inoculation with *P. oryzae*. Sodium in leaf tissues from upland plots did not vary appreciably during the season, averaging 299 ppm and 248 ppm for M-201 and Brazos; in flooded plots the sodium in leaves of Brazos rapidly decreased as plants aged and, at 28 days after initial sampling, became the same as that in leaves from upland plots. Sodium content in leaves of M-201 gradually declined as the season progressed. No apparent changes in sodium content occurred in either cultivar when upland plots were flooded or when flooded plots were drained.

Iron content did not vary between varieties or treatments, nor did the contents of zinc (about 35-45 ppm), aluminum (42-52 ppm), or copper (about 16 ppm).

IMPLICATIONS OF THE RESEARCH

Observations have been made since the early 1900s that rice blast in upland conditions is more severe than in flooded conditions. Our research confirms these observations through field tests conducted under controlled conditions. It also shows that microclimatic factors have little or no effect on blast development.

Under upland conditions, lesion number, but not lesion size, was significantly increased, as was the number of conidia produced in each lesion. Reduction of these factors in susceptible varieties by flooding suggests that flooding causes a change in the dilatory or partial resistance as described by Parlevliet (1979). M-201 was selected as a test variety because it was recommended by Dr M.A. Marchetti as having little or no partial resistance to blast. Dr Marchetti also recommended the variety Brazos for our test because it was a variety susceptible to several races of *P. oryzae*, but having a relatively high level of partial resistance as described in his testing procedure (Marchetti 1983). When upland plots of Brazos were flooded, the variety became resistant after a short lag, whereas M-201's resistance level increased only slightly and did not slow the rate of disease development.

These findings suggest that one can compare levels of partial resistance of rice varieties and lines by growing them in nurseries under upland conditions until an epidemic is established and then flooding the plots and comparing the recovery from blast over time.

When both varieties were flooded at the seedling (early tillering) stage and the flood was maintained throughout the growing season, they reacted as though they had a high level of partial resistance.

A similar result has recently been obtained in preliminary experiments in the greenhouse where a gradient was established in the soil from flooding to dry soil barely sufficient for plant growth. An environment equally favourable for infection and disease development was maintained for the foliage of all of the plants. Infection was significantly higher on plants in saturated and progressively drier soil than on plants growing in flooded soil. This suggests that a change in the physiology of the plant, related to reduced conditions in the soil, mediates resistance of leaves to rice blast.

At present, we are investigating the effects of flooding on nitrogen, silica, sodium, sulfur, magnesium, and manganese in leaves and the effects of these elements on resistance to leaf blast. We are also investigating the histopathologic changes caused by infection. Included are studies of infection site on the leaf surface, success of infection, and development of hypersensitivity under conditions of reduced and oxidized soil.

Sheath rot disease in tropical Africa

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Abstract *Sheath rot disease, which is widespread on rice grown in Africa, causes poor panicle formation and exsertion, tiller stunting, spikelet sterility (80–100%), reduced grain filling, husk and caryopses disease, losses in milling, preharvest germination of grains and, consequently, reduced yield. Dwarf, high-yielding cultivars are more susceptible than taller ones, and plant metabolism in relation to susceptibility has been described. Much confusion surrounds the causal organisms and hinders the development of effective control programs. Sawada (1922) first described the disease from Taiwan, naming the causal fungus* Acrocylindrium oryzae *Sawada. This fungus is now called* Sarocladium irtzae, *and another causal pathogen has been described* — S. attenuatum. *The latter has been shown to have been erroneously called* A. oryzae *in past reports on the disease.* Fusarium moniliforme, F. equiseti, *and* Curvularia lunata *have also been isolated from (and have been shown to cause) sheath rot and rice grain discoloration. Although the specific role of insects is yet to be resolved,* S. oryzae, S. attenuatum, *and other pathogens can cause sheath rot and grain discoloration independently of stem borer damage and other predisposing factors. Conidial dispersal, seeds, and weed hosts may be important means of transmission.*

Sheath rot of rice has been little studied; yet it is a serious threat to increased rice production in tropical Africa. It was first described by Sawada (1922) from Taiwan. The causal fungus was named *Acrocylindrium oryzae* Sawada and is now known as *Sarocladium oryzae* (Sawada) W. Gams & D. Hawksw. It is present in Japan and is common in Southeast Asia and on the Indian subcontinent (Agnihothrudu 1973; Amin et al. 1974; Chin 1974; Nair 1976), in the USA in Louisiana (Shahjahan et al. 1977), and in West and Central Africa where it is a major problem in upland rice, especially on the cultivars introduced from Asia (Ngala 1982). The disease is present in Ghana, Côte d'ivoire, Liberia, Sierra Leone, Togo, Nigeria, Cameroon, Mozambique, Kenya, and SeneGambia (Brady 1980; Ngala 1982; CMI 1985).

The rot occurs on the uppermost leaf sheaths enclosing the young panicles. The lesions start as oblong or somewhat irregular spots 0.5-1.5 cm long, with brown margins and gray centres, or they may be grayish-brown throughout. They enlarge and often coalesce and may cover most of the leaf sheath. The young panicles either remain in the sheath or emerge partially, depending on the severity of the disease. An abundant whitish powdery growth may be found on the affected sheath, especially early in the morning or in wet weather. In dry weather the powdery growth may be found only inside the affected sheaths, and the young panicles are rotted. The fungus also causes browning of the grains and the inner surface of the leaf sheath, which looks normal from the outside.

Although Sawada (1922) described the causal organism early this century, it was known only in Chinese and Japanese literature until Ou (1972) published an English review, giving a photograph of the disease symptoms. Agnihothrudu (1973) and Amin et al. (1974) described cases of Indian sheath rot, which they considered to be caused by *A. oryzae*. Gams and Hawksworth (1976) studied these organisms, comparing the isolates with each other and with Sawada's holotype material and decided that the two were different species. As the genus *Acrocylindrium* deals with *Verticilium*-like species for which the type material has been lost, Gams and Hawksworth (1976) introduced the new genus *Sarocladium* and proposed that *S. oryzae* (Sawada) W. Gams & D. Hawksw. be the type species including Amin's fungus. The other isolate, which they considered to be erroneously named by Sawada and which agreed with Agnihothrudu's material, was described as a new species *S. attenuatum* W. Gams & D. Hawksw. Unfortunately, some confusion still exists, as authors continue to refer to *A. oryzae* (Purkayastha and Anima Ghosal 1982; Ou 1985). Holliday (1980) expressed doubt that *S. attenuatum* causes sheath rot of rice, but studies in Nigeria at IITA and the University of Ibadan (Ngala 1980, 1982, 1983) have confirmed it and have shown that *S. attenuatum* is one of the major pathogens causing discoloration of rice grain in Africa. Ou (1985) stated that for simplicity the sheath rot fungus should be called *S. oryzae* because the symptoms reported for the two fungi are, in any case, extremely similar. However, many other fungi like *Fusarium moniliforme, F. equiseti*, and *Curvularia lunata* have been isolated (Ngala 1982; Kang and Rattan 1983) from plants with symptoms of sheath rot and have been shown to cause both sheath rot and rice grain discoloration. These observations point to the need for more work on sheath rot so that proper control measures can be taken.

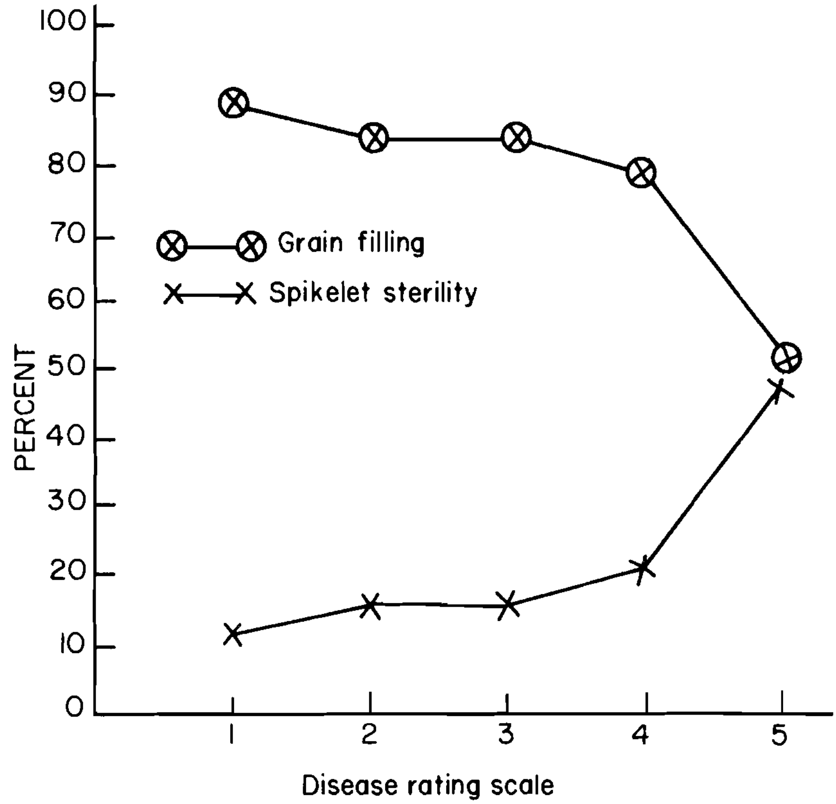

Fig. 1. Relation between score for disease severity and the percentage of spikelet sterility and of grain filling.

Although *S. oryzae* and *S. attenuatum* may be the major causal organisms, the roles of other pathogenic fungi being reported, and the effects of their interactions in sheath rot disease, should not be underestimated.

INTERACTIONS, TRANSMISSION, AND EFFECTS

Ou (1972) stated that the fungi tend to attack the leaf sheaths enclosing the young panicles when there is an injury that retards the emergence of the panicles. Amin et al. (1974) reported that the disease was severe in densely planted fields and those infested by stem borers. Chin (1974) found that while the disease occurred in injured and uninjured plants, severe development occurred only in injured plants or those attacked by stem borers. Hsieh et al. (1977) found *S. oryzae* associated with a mite, *Steneotarsonemus madecassus*, and

S. *attenuatum* has been isolated from *Nilaparvata lugens*, the brown planthopper of rice (Brady 1980) — findings that suggest insect transmission.

Although fungal attack is often associated with damage by insect pests, such damage is not a prerequisite for the occurrence of sheath rot disease (Agnihothrudu 1973; Ngala 1982, 1983). *Sarocladium oryzae* and *S. attenuatum* are seedborne and may also be transmitted by conidial dispersal in the air.

During the 1980-83 crop seasons, one of us (Ngala 1980, 1982, 1983) conducted studies to determine the direct effects of *S. attenuatum* on the growth and performance of rice plants. When BG 6850 (ITA 212) was inoculated between panicle initiation and booting stages under greenhouse and field conditions, the pathogen caused poor panicle formation and exsertion, tiller stunting, and 80-100% spikelet sterility. Spikelet sterility increased and grain filling decreased with an increase in disease severity (Fig. 1). In some

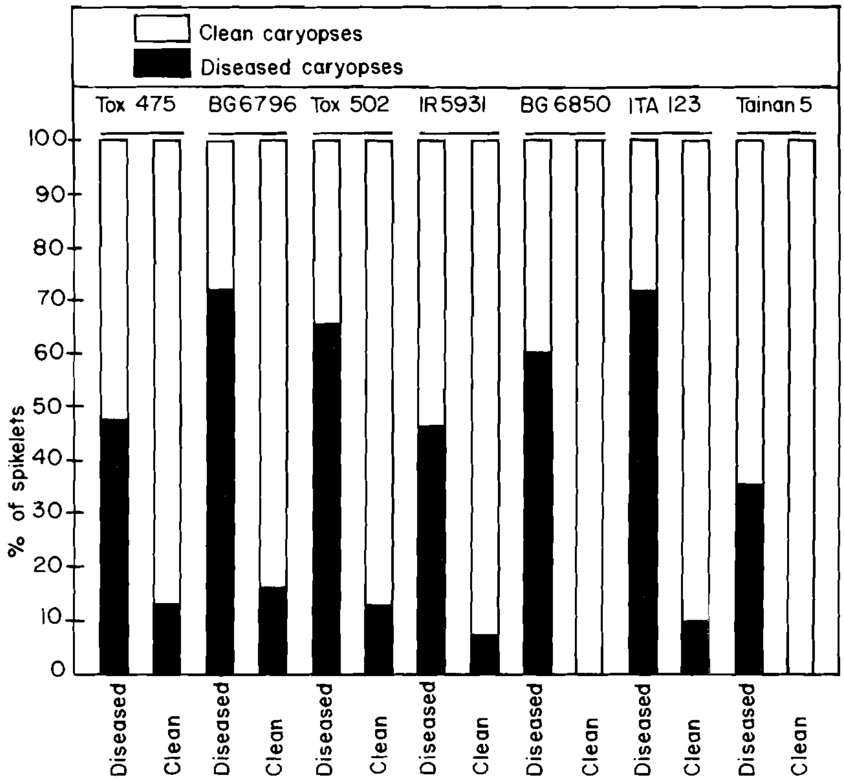

Fig. 2. The relation between husk and caryopsis disease.

severe infections, both under field and greenhouse conditions, panicles failed to form. Infected husks (judged by discoloration) resulted in infected caryopses (Fig. 2), and shriveled grains resulted in losses in milling. Preharvest germination of grains on the panicle was induced in Norin 6, Ngovie, and BG 6812 under the humid mid-August field conditions of Ibadan. Caryopses' infection resulting from infected grains was 5–73% in seven rice cultivars (Fig. 2). Diseased caryopses and husks reduced viability and total grain yield as well as increasing seed rot in the soil. These effects demonstrate the potential of *S. attenuatum* to reduce rice yield.

A few reports from abroad state that the damage caused by sheath rot disease is sometimes high, with damage varying from 3% to 85% and reported yield reductions being 10–26% among the few cultivars examined (Chen 1957; Chakravarty and Biswas 1978; Ou 1985).

CULTIVAR RESISTANCE, HOST RANGE, AND CONTROL

The dwarf cultivars of rice are more susceptible than the taller ones (Amin et al. 1974; Brady 1980; Ngala 1982), but even they vary greatly in susceptibility. Asian germ plasm is generally more susceptible than African. Screened with the boot infiltration technique in the field and greenhouse, TOx 86-1-3-1 (ITA 116) was the most resistant cultivar tested. HR 11-1 and TOx 1835 were resistant, and TOx 1837 was fairly resistant. TOx 728-1, IR5931-81-1-1, BG 6796, and IRAT 13 were all susceptible to *S. attenuatum* (Ngala 1982). Host plant metabolism in relation to susceptibility to *S. attenuatum* has been described elsewhere (Mohan and Subramanian 1980).

Information on the host range of *S. oryzae* and *S. attenuatum* is gradually increasing. Up to 1980 the two species were known to occur only on rice (Brady 1980), but weed hosts such as *Echinochloa colona, E. crus-galli, Cyperus difformis, C. iria, Eleusine indica,* and *Monochoria vaginalis* have now been reported (Balakrishnan and Nair 1982; Rahman et al. 1982) for *S. oryzae.*

Research on the control of these pathogens is still in its infancy. The work to date has been mainly with chemicals: benlate, difolatan, and bavistin being effective and popular. More studies are needed, especially into measures of cultural and biological control. Use of resistant cultivars is probably the most suitable means of control.

CONCLUSIONS

Sheath rot is now known to be a major problem in Africa and almost coexists with the rice crop. Losses caused by the disease vary from one area to another and from year to year, depending on the environmental conditions and genetic constitution of both the host cultivar and the pathogen. We therefore suggest that in national programs efforts be devoted to:

- Identifying resistant, local cultivars;
- Using those identified in breeding work and extensive cultivation by local farmers;
- Ensuring that seed distribution to local farmers is undertaken by national programs with some measures to guarantee the seed is pathogen free;
- Encouraging cooperation among breeders, agronomists, pathologists, entomologists, and physiologists in selecting recommended cultivars;
- Adapting the integrated pest-management approach for control measures; and
- Ensuring that local farmers are familiar with the problem on their rice fields and that they will report immediately any signs of the disease.

Considering the limited information from tropical Africa itself and the destructive potential of the pathogens on the crop, we believe that more studies on the disease and increased international cooperation merit immediate attention.

Iron toxicity of rice in inland valleys: a case from Nigeria

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Abstract *A field study was conducted in a small inland valley (20 ha) near Bende in southeastern Nigeria to characterize the source and dynamics of reduced iron in the soil and to delineate zones in the field. Groundwater tables and the concentration of ferrous ion in the soil solution were monitored throughout the year. Results showed that severe iron toxicity (indicated by bronzing in rice) occurred near the seepage outlets where the concentration of ferrous ion (Fe^{++}) exceeded 20 ppm during the growing season. The soils in the iron-toxic area remained permanently saturated at shallow depths. The soils were grayish, with few mottles in the subsoil horizons. The groundwater table in the nontoxic area showed large fluctuations throughout the year and dropped below 100 cm during the dry season. The concentration of ferrous ion in the soil solution was low (0–5 ppm) during the wet season. The hydromorphic soils in the nontoxic areas had good structure in the surface layer and many mottles, which extended more than 100 cm deep. Based on the ferrous concentrations in the soil solution and the expression of symptoms of toxicity in a susceptible rice variety, IR26, the field was divided into three iron-toxic zones to be used for screening of rice cultivars for tolerance to iron toxicity.*

In subsaharan Africa, lowland rice is grown without water control in many inland valleys or depressions. Deep flooding is seasonal and frequently damages the crops during early growth. Iron toxicity is also common in many inland valleys, where seepage flows or springs contain high concentrations of ferrous ion (Fe^{++}). In one of these (about 20 ha) near Bende in southeastern Nigeria, we conducted a field study to characterize the source and dynamics of reduced iron in the soil and to delineate zones in the field that could be used for screening of rice varieties for tolerance to iron toxicity.

The Bende area consists of undulating land forms with small residual hills formed from sandstone. The valleys or swamps are mostly U-shaped, with underlying tertiary shales. The small inland valleys have steep side slopes; thus, no hydromorphic soils are found in the foot slopes of the toposequence. The valleys range from 20 to 100 ha.

The hydromorphic soils at the valley bottoms are generally high in organic matter, weakly acidic, fine, with high levels of exchangeable Ca, Mg, and K, and a montmorillonitic clay mineralogy (Table 1). The pedon is classified as a Eutric Tropaquept and has a blocky structure and high base status. It is the most fertile rice soil among the pedons observed in the wetland areas in southern and southeastern Nigeria. Several inland valleys in the Bende area have been developed for irrigated or rainfed lowland rice cultivation. Rice with various degrees of iron toxicity symptoms can be observed in the Bende wetlands.

Field observations showed that severe iron toxicity (indicated by bronzing in rice) occurred mainly near the seepage outlets in one of the small side valleys (Fig. 1). The soils there were poorly drained and grayish, with few mottles in the subsoil horizons.

Hydromorphic soils in the nontoxic area had good structure in the surface layer and many mottles, which extended more than 100 cm deep. Clearly, the groundwater table in the nontoxic area dropped to below 100 cm and allowed oxidation to take place during part of the year.

SITE CHARACTERIZATION

Along the direction of the seepage flow, we installed six groundwater tubes, of which four were placed along a transect from the foothill to the main stream, covering both the Fe-toxic and nontoxic areas of the valley (Fig. 1). The groundwater table at each tube was recorded weekly during the wet and dry seasons, and samples of soil moisture were withdrawn once a week for analysis of soluble Fe^{++}.

Rice variety IR26, which is highly susceptible to Fe toxicity, was planted uniformly across the field. Based on the ferrous concentrations in the soil solutions and the expression of symptoms of toxicity in the rice (bronzing and various degrees of oranging), the field was divided into three Fe-toxic zones (Fig. 2): in zone A, IR26 showed severe bronzing and gave little or no grain yield; in zone B it showed severe oranging and some bronzing, and in zone C slight oranging. Zone D was nontoxic.

Fluctuations in the groundwater table during the growing season are related to topography, seepage, and groundwater flow. In this study, groundwater data indicated that soils in the iron-toxic

Table 1. Properties of some hydromorphic soils from inland valleys near Bida and Bende and from the allluvial plains of the Anambra River near Adani, southern and central Nigeria.

Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	pH	Organic C (%)	Exchangeable cations (meq/100 g)						CEC (meq/100g)	Bray P-1 (ppm)
							Ca	Mg	K	Na	Al	H		
Arenic Tropaquept, Gara fadama, Bida														
0-10	Ap	68	30	2	4.2	1.10	0.96	0.15	0.13	0.07	0.68	0.04	2.10	9.6
10-23	A2	72	26	2	4.2	0.27	0.85	0.06	0.06	0.04	0.49	0.00	1.55	12.0
23-42	B2	50	38	12	4.1	0.58	1.60	0.27	0.05	0.04	0.86	0.00	2.82	1.8
42-80	C1	50	46	4	4.3	0.32	0.41	0.08	0.06	0.03	0.61	0.00	1.22	2.2
Plinthic Tropaquult, lower terrace, Adani														
0-4	Ap	14	72	14	4.2	1.78	0.60	0.48	0.16	0.06	1.86	0.68	3.94	3.9
4-7	A12	18	56	26	4.9	1.12	1.10	2.42	0.22	0.06	1.18	0.28	5.98	1.2
7-20	B1	16	50	34	4.6	0.77	0.90	3.38	0.16	0.06	2.90	0.88	8.52	0.6
20-80	B2	18	48	34	4.6	1.42	0.80	4.28	0.25	0.06	3.94	1.31	10.74	0.4
Typic Tropaquept, floodplain, Adani														
0-12	Ap	16	38	46	4.3	1.54	6.60	5.45	0.38	0.15	0.75	0.04	13.77	1.5
12-37	B2	14	38	48	5.4	0.58	6.80	6.45	0.35	0.18	0.14	0.00	13.94	0.6
37-60	B3	14	38	48	5.6	0.95	7.60	6.70	0.35	0.19	0.18	0.00	15.02	0.6
60-100	C	20	38	42	5.5	0.60	7.00	6.80	0.29	0.21	0.21	0.00	14.54	0.5
Eutric Tropaquept, inland swamp, Isi-Ugwu, Bende														
0-13	Ap	18	33	49	4.6	4.56	23.10	4.42	0.41	0.11	0.35	0.06	28.59	4.5
13-35	B2	14	35	51	5.5	2.13	26.30	4.82	0.33	0.10	0.09	0.00	31.69	2.2
35-65	B3	14	35	51	5.7	0.58	24.40	4.50	0.31	0.09	0.14	0.00	21.45	1.2
65-100	C	14	35	51	5.4	0.36	24.60	4.67	0.33	0.10	0.06	0.09	30.86	0.9

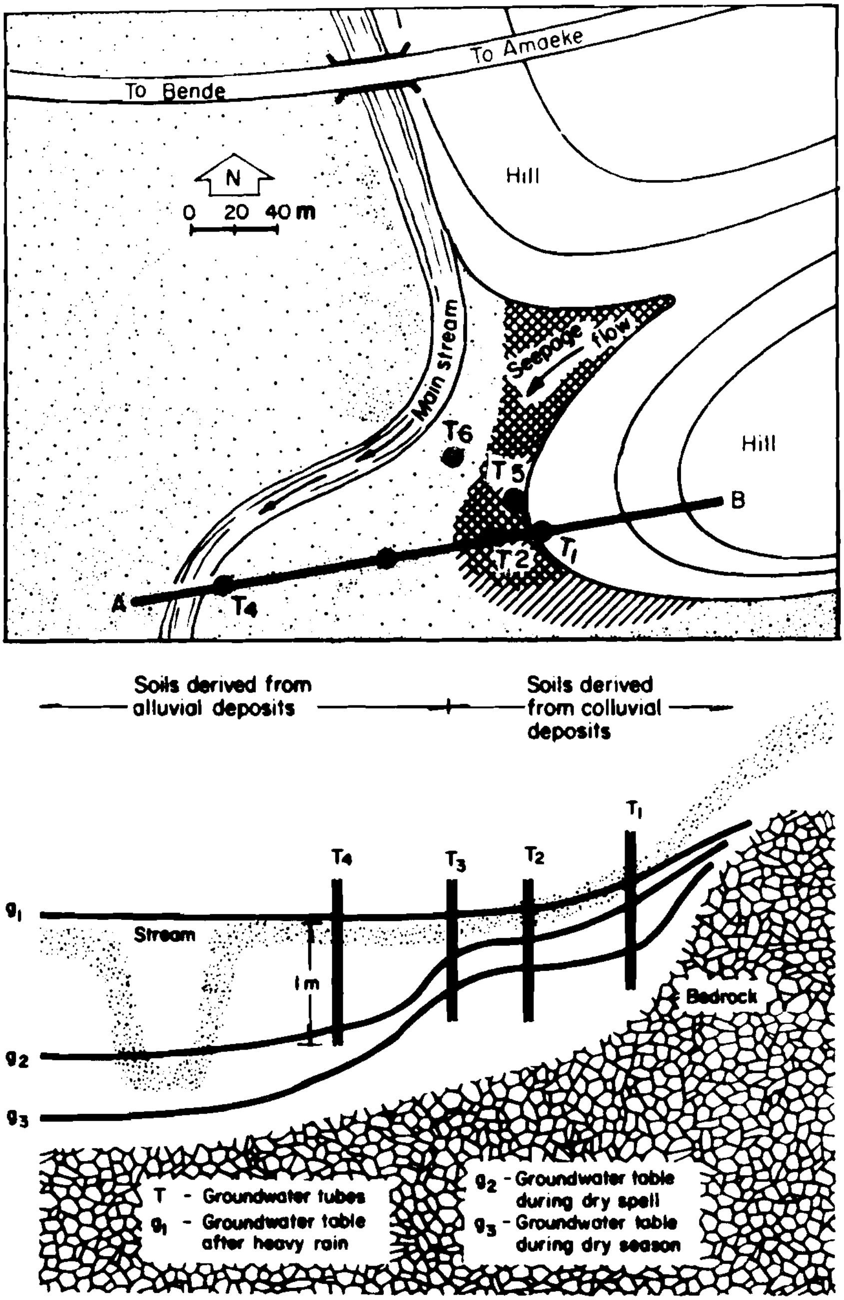

Fig. 1. Landscape, locations of groundwater tubes, and seasonal fluctuations of groundwater table, Bende valley, Nigeria.

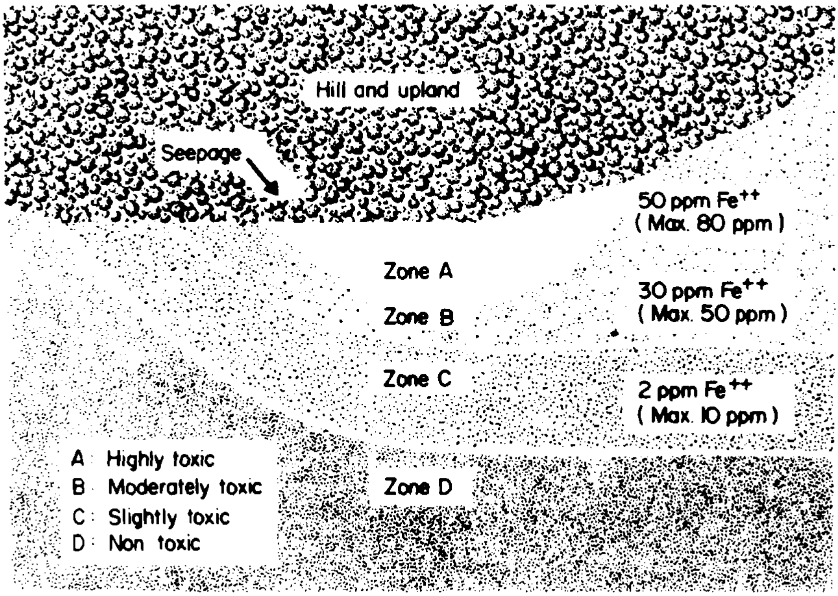

Fig. 2. Isolines of mean and maximal concentrations of ferrous ion in samples of soil solution as a reflection of the symptoms of iron toxicity exhibited by a susceptible variety of rice, Bende valley, Nigeria.

area (tubes 2 and 5) remained saturated or flooded throughout the growing season (Fig. 3). Their soil solutions contained high levels of soluble iron, ranging from 20 to 50 ppm (Fig. 4). The highest content of soluble iron was observed in water samples taken from tube 5, which apparently was close to the source of seepage flow and was subjected to continuous flooding.

In the nontoxic area, the groundwater table fluctuated markedly during the growing season (tubes 3 and 4, Fig. 4), and the soluble Fe in the soil solution was from 0 to 5 ppm (Fig. 4).

Analysis of data collected throughout the year indicated that the depth of the groundwater table in the valley bottoms varies greatly between the rainy and dry seasons. During most of the rainy season, it remained near the surface. The surface soil in the toxic area was thus enriched by the seepage water containing high ferrous concentrations that caused toxicity in rice near the outlets of seepage. During the dry season, starting at the end of November, the groundwater table dropped gradually to the level of the main stream (tubes 4 and 6, Fig. 1). Seepage flow from the side valley also diminished during the dry season, and a slight drop of the groundwater table in the Fe-toxic area allowed oxidation to take place in the surface layer during some part of the dry season.

Fluctuations in the groundwater table during the rainy season

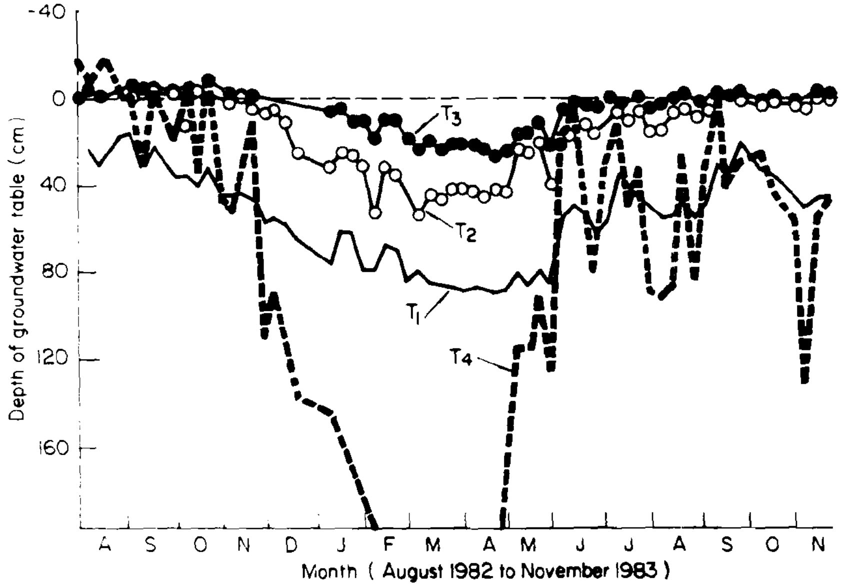

Fig. 3. Depth of groundwater table at different sites in Bende valley, Nigeria, between August 1982 and November 1983 (rainy season is April-November).

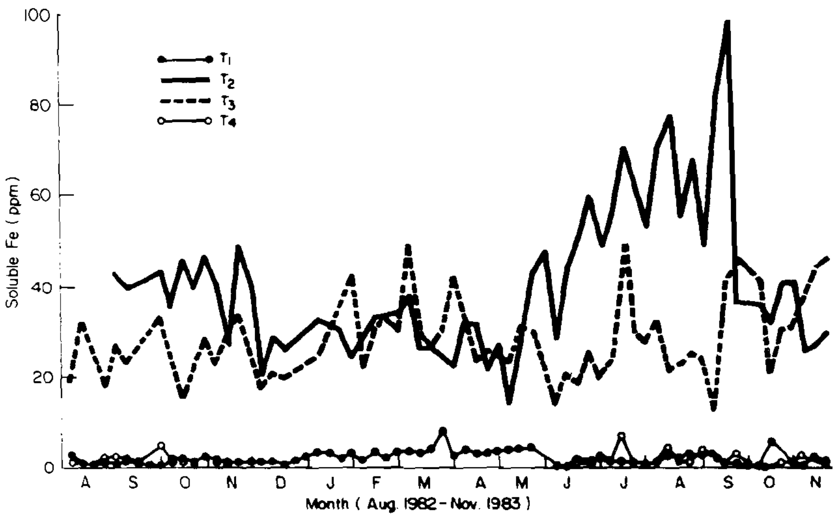

Fig. 4. Concentrations of ferrous ion in samples of soil solution, August 1982 to November 1983, Bende valley, Nigeria.

followed the rainfall pattern, but their magnitude varied from one site to another, depending on soil type (Fig. 1 and 3). Although the nontoxic zone was situated in the lowest part of the landscape, the tubes in this zone (tube 4, Fig. 3) showed the largest fluctuations in groundwater table throughout the year. This finding indicates that the nontoxic area is better drained than the toxic area, even though the latter is on higher land (tubes 2 and 3, Fig. 3). Because of the nontoxic area's greater distance from the seepage source and its large fluctuations in groundwater and redox potential, the ferrous ion in the soil solution either drained out with groundwater or was oxidized and precipitated as ferric oxides (Fig. 3 and 4). In contrast, soils in the Fe-toxic area (tubes 2 and 5, Fig. 1) remained almost permanently saturated, and at shallow depths throughout the year (Fig. 3 and 4).

This quantitative characterization of the Fe-toxic site has allowed rice breeders to use the area for screening rice cultivars for tolerance to conditions causing iron toxicity.

PLANT RESPONSE

A field survey of rice being screened in the area was also conducted. In a strongly reduced field containing toxic levels of ferrous ion, the

Two varieties of rice grew side by side in soil with high concentrations of ferrous ion. The susceptible variety, left, suffered root rot and leaf bronzing, whereas the tolerant variety maintained an oxidized rhizosphere as protection against toxicity.

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presence of tolerance in some varieties was obvious and the levels of susceptibility varied markedly among the varieties.

The susceptible plants generally showed two types of symptoms on fully developed leaves: bronzing, which indicates acute Fe toxicity, and oranging, which generally occurs in fields containing moderate levels of ferrous ion. Oranging leaves seemed to reflect nutritional disorders resulting from a malfunction of the rice roots rather than direct effects of Fe toxicity.

Roots of a highly susceptible variety simply could not survive in strongly reduced soil containing high levels of ferrous ion. A moderately tolerant variety, in contrast, maintained an oxidized rhizosphere, causing ferric oxides to precipitate on the root tips and surfaces. The surface coating of ferric oxides inhibited normal nutrient and water uptake by the roots, and the result was oranging leaves. Tolerant varieties, however, not only were capable of maintaining an oxidized condition at the root-soil interface, but also had more vigorous root systems.

CONCLUSIONS

In inland valleys and swamps in Africa, toxic levels of iron (Fe^{++}) are a widespread but localized problem, where seepage flows contain a high concentration of ferrous ion and the soils are strongly reduced throughout the year because of a high groundwater table. However, the extent and the severity of the problem depend largely upon the volume of the seepage flow, the source and the concentration of ferrous ion, the groundwater table, and the drainage near and below the seepage flow.

The hydromorphic soils of the inland valleys near Bende are among the most fertile soils for lowland rice cultivation in Nigeria. Of the total area in our study an estimated 5–10% represented conditions where iron toxicity would be a problem. Reclamation of this area could be achieved by the construction of a small drainage canal to lead the iron-rich seepage water into the main stream. At present, the toxic area is being used for screening rice cultivars.

We wish to thank F. Ndubuka of the Imo State Rice Project and K. Alluri of IITA for their technical cooperation and advice.

Weed management

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Abstract *Although the damage caused by weeds depends on water management, weeding frequency, and cropping pattern, yields of rainfed rice in the wetlands of Africa are reduced an average 40% by weeds.* Cyperus, Commelina, Paspalum, Echinochloa, Ipomoea, Cynodon, Ischaemum, *and* Sphenoclea *are the major genera interfering with rainfed lowland rice, whereas* Oryza barthii, O. longistaminata, Ipomoea aquatica, *and* Eleocharis plantaginaea *limit yields of deepwater rice. At present, weed control is mainly by hand (pulling and hoeing), the time being estimated at about 250–780 h/ha. Puddling, harrowing, and flooding can reduce weed infestation, as can planting rice at close spacings and rotating rice with upland crops. Biological control includes use of tadpole shrimps on plots with well-established seedlings. Several herbicides in combination with propanil have been shown to be effective. Management practices that incorporate cultural, biological, and chemical control are the focus of current weed research, as no one method of control is sufficient.*

Weed problems found in the wetlands vary with the type of water management practiced. The most serious are found in the valley bottoms and hydromorphic soils where rice production depends on uncontrolled flood water and rainfall — areas known as fadamas. The soils in these areas are too moist for effective use of mechanical weeders, and the levels of water cannot be easily manipulated for weed control. Also, the warm, moist conditions of hydromorphic soils favour the rapid breakdown of soil-applied herbicides, thereby reducing their efficacy (Akobundu and Fagade 1978).

The major weeds of inland river valley bottoms and floodplains are *Cyperus* spp., *Commelina* spp., *Paspalum* spp., *Cynodon dactylon, Ischaemum rugosum, Echinochloa* spp., *Sacciolepis* spp., *Sphenoclea zeylanica, Ipomoea* spp., and other broadleaf weeds that can survive in both aquatic and dryland conditions. In the savanna, the fadamas are taken over by tall grasses such as *Panicum* spp., *Hyparrhenia* spp., etc., increasing the problem of dryland crop production during the dry season. Weeds of mangrove swamps (deepwater rice) consist of *Oryza barthii, O. longistaminata, Ipomoea aquatica*, and *Eleocharis plantaginaea* (Nyoka 1983). Weed-crop associations in the wetlands are affected by the cropping history of the fields.

WEED INTERFERENCE

Weeds interfere with crop growth by competing for nutrients, water, and light. Boerema (1963) reported that nitrogen uptake by rice plants in the presence of weeds was 26% compared with 99% when weeds were few or absent. Weeds also affect crop growth by introducing allelochemicals into the environment they share with crops. The effects of weed interference may be subtle at first — reduced plant vigour, delayed development or suppression of specific characters.

Untimely weed control is common among small-scale farmers in Africa, mainly because the farmers do not know the extent to which seedling weeds adversely affect crop plants during the early stages of crop establishment. Ultimately, weeds reduce crop yield if they are not removed during the period that the crop is most sensitive to them.

Yield losses caused by uncontrolled weed growth in rice in West Africa range from an average of 40% in lowland rice to 100% in dryland rice (Table 1), depending on water management, weeding frequency, and whether the rice is direct-seeded or transplanted (Akobundu and Fagade 1978).

The extent of yield reduction is also affected by rice cultivar and row spacing. In one earlier study (Akobundu and Ahissou 1984), the yield of a tall OS 6 rice cultivar, which was weeded only once in a hydromorphic soil, was reduced by 39%, while a semidwarf cultivar, ADNY 11, suffered a yield reduction of 63% at the same spacing and weeding frequency. Rice in the control plots in that study was maintained weed free until crop harvest.

Weeds affect tillering, panicle number, and number of grains per panicle (Ahmed and Moody 1980; Akobundu and Ahissou 1984). Although flooding controls many aquatic weeds, deepwater rice starts off as dryland rice and will yield well only if protected from weed interference before flooding occurs.

One of the most labour-demanding operations in rice production is weed control. Hand-weeding in many rice-producing countries has been estimated to require 250–780 h/ha, depending on the ecosystem, frequency of weeding, water management, and the environmental

Table 1. Average yield reduction caused by uncontrolled weed growth (Akobundu and Fagade 1978).

	Yield reduction (%)
Upland	
Gambia	100
Ghana	84
Liberia	39-87
Nigeria	80-100
Senegal	48
Burkina Faso	62
Lowland	
Transplanted	
Liberia	44-51
Nigeria	33-75
Senegal	28
Direct seeded	
Ghana	28
Nigeria	46-84

conditions during cropping (Dadey 1973; De Datta et al. 1973; Matsunaka 1975).

Land preparation also affects level of weed infestation. For example, *O. longistaminata* infestation in rice can be minimized if the field is deeply plowed twice before the onset of the dry season, preceding the next rice cultivation (Nyoka 1983).

WEED MANAGEMENT

No single method will give effective weed control in all rice-cropping systems. A range of weed-management strategies needs to be evaluated for crop production in wetlands so that the techniques available can be matched to the cropping system and the resource base of the farmers.

Breeders and agronomists normally evaluate yield potentials of rice cultivars under weed-free conditions often without reference to the ability of the "improved variety" to compete with weeds under conditions in which the farmer will grow the crop. Yet, increased yields from use of improved rice cultivars cannot generally be realized without improved methods for weed control, including cultural, biological, and chemical control.

CULTURAL METHODS

Cultural weed control refers to all types of soil disturbances and physical manipulation of the vegetation to provide weed-free conditions for crop growth. It is the main method used for rice production by small-scale farmers. Weeding is by hand (hoeing as well as pulling the weeds) or by machines that are pushed by humans, drawn by animals or tractors, or self-propelled and requiring only steering by an operator. The effectiveness of mechanical weeders depends on soil moisture and the extent to which water depth can be manipulated by the farmer.

Hand weeding is slow and labour intensive; it is recommended only where human labour is cheap and readily available; the intensity of weed infestation is low; crops are known to be highly competitive with weeds; farm sizes are small; weeds are known not to cause economic losses in crops; and good water management is part of rice production already practiced or available to farmers. The time spent weeding in direct-seeded rice can be reduced if the crop is planted in rows, and if weeding is done on time.

Hand pulling of weeds may be the only practical option for weed removal in, for example, flooded paddies. However, not all weeds can be controlled by hand-weeding: *Commelina* spp., *C. dactylon*, and *O. longistaminata* are perennial problems.

All forms of mechanical weeders require fewer hours for weed removal than hand weedings, but generally they do not have yield advantages. Navasero and Khan (1970) reported no difference in weed weight at rice harvest between plots that were weeded mechanically and those weeded manually, but the latter was a more expensive method. In hydromorphic soils and paddies without water control, mechanical weeding is not always effective because weeds removed with a ball of earth around the roots merely get transplanted rather than destroyed. Crop yield in mechanically weeded rice is lower than in hand-weeded plots possibly because the rotary weeder does not remove weeds that are within or close to the rice hills (Navasero and Khan 1970; De Datta 1981).

Land preparation, particularly puddling, is an effective method of weed control (Table 2) with the number of harrowings being related to weed pressure in lowland rice. Vargas (1978, cited by De Datta 1979) reported that weed biomass in broadcast-seeded rice decreased with increase in the number of harrowings done in the

Table 2. Effect of different methods of planting and land preparation on weeds growing in association with rice 4 weeks after planting (adapted from Moody 1977b).

Methods of land preparation and planting	Weeds (% of total)			Weed weight (kg/ha)
	Broad-leaves	Grasses	Sedges	
Puddled, wet-seeded	57	35	8	72
Puddled, transplanted	83	7	10	106
Dry (rainfed), bunded	33	64	3	1582

Table 3. Effect of land preparation and weed control on weed weight at 60 days after crop emergence (adapted from IRRI 1981).[a]

Land preparation method	Weed weight (g/m²)			
	No weeding	Hand weeding × 2	Thiobencarb + propanil	Pendimethalin + propanil
Zero tillage	1037a	91a	256a	227a
1 plow, 1 harrow	1092a	98a	416a	119ab
1 plow, 3 harrows	818ab	42ab	302a	165ab
Stale seedbed, harrow	293bc	18bc	15bc	133ab
Stale seedbed, paraquat	215c	11c	40b	45b

[a]By column, values followed by the same letter do not differ significantly at the 5% level of probability.

plowed land. Thorough land preparation reduces weed pressure, and the use of postemergence herbicides, in turn, reduces the need for many harrowings (Table 3).

Yield reductions caused by weeds in lowland rice can be minimized by water management (Martin and Guegan 1973) because many weeds will not germinate under flooded conditions. However, a majority of the small-scale farmers in West Africa lack the technology for leveling the fields so are unable to manage water properly. Direct-seeded rice is generally more susceptible to weed infestation than is transplanted rice, but both give identical yields when weeds are controlled (De Datta et al. 1969). Maximum benefit comes from flooding done when the weeds are seedlings and when water is kept 10–20 cm deep.

BIOLOGICAL METHODS

Biological methods of weed control are those involving the suppression of weeds by insects, plants, microorganisms, macrobial agents, etc. In Asia, tadpole shrimps (20–30/m²) have been used successfully for weed control in transplanted rice with roots that are adequately covered with soil (Matsunaka 1976, 1979). However, the shrimps are not selective in the type of vegetation they eat and have been known to damage seedlings and roots of direct-seeded rice. Also, any large-scale application of this method of control depends on successful mass rearing and conservation of shrimp eggs and on proper timing of insecticide applications to minimize damage to the tadpole shrimps.

Another example of biological control is mycoherbicides such as Collego®, which is the dry conidia of the fungus *Colletotrichum gloesporioides* f sp. *aeschynomene*. It has been registered for the

Table 4. Effect of interrow spacing and weeding frequency on grain yield (t/ha) in selected rice cultivars (Akobundu and Ahissou 1984).

	Inter-row spacing (cm)	Cultivar OS 6	ITA	ADNY 11	Weeding × spacing
Weeded once	15	2.7	2.3	3.1	2.7
Weeded twice	15	2.8	2.7	3.1	2.9
Weed free	15	3.4	3.3	3.9	3.5
Weeded once	45	2.2	2.7	1.5	2.0
Weeded twice	45	2.7	2.6	2.9	2.7
Weed free	45	3.6	3.6	4.1	3.8
LSD (P = 0.05)		0.3	0.3	0.3	0.4

control of northern jointvetch (*Aeschynomene virginica*) in rice (Daniel et al. 1973).

Other types of biological control involve manipulation of population densities, interrow spacing, and the inherent ability of rice plants to compete with weeds. For example, we at IITA (Akobundu and Ahissou 1984) showed that an improved cultivar of dwarf rice grown in rows 15 and 30 cm apart yielded better than in rows 45 cm apart (Table 4). Moody (1977a) reduced weed density significantly in lowland rice by increasing rice seeding rate from 80 to 200 kg/ha, but the increases in grain yield were not so impressive (Table 5). Crop rotation also reduces weed populations. For example, rotating lowland rice with upland crops results in reduced infestation of water-tolerant weeds such as *Scripus maritimus* in the rice crop (Smith 1967; Jereza and De Datta 1977) (Table 6).

CHEMICAL METHODS

Chemical weed control in rice production is still in its infancy in Africa. Herbicides offer the most practical, effective, and often the most economic means of reducing crop losses. Several herbicides

Table 5. Effect of seeding rate on weed weight and grain yield of wet-seeded rice (adapted from Moody 1977a).

Seeding rate (kg/ha)	Weed weight (kg/ha)	Yield (t/ha)
80	1.7	4.3
120	1.2	4.3
160	0.9	4.4
200	0.6	4.5

Table 6. Effect of cropping system on the population of annual and perennial weeds in lowland rice in unweeded check plot (adapted from De Datta 1979).

	Cropping system 1			Cropping system 2		
		Weeds/m^2			Weeds/m^2	
Season	Crop	Annual	Perennial	Crop	Annual	Perennial
1976	Dry lowland rice	990	205	Maize + bean	1571	60
1976	Wet lowland rice	1168	300	Lowland rice	639	191
1977	Dry lowland rice	277	191	Maize + soybean	620	59
1977	Wet lowland rice	88	421	Lowland rice	176	209

used singly and in combination have been evaluated for weed control and for their effects on crop yield in direct-seeded lowland rice under poor water management — the conditions in which lowland rice is grown by most farmers in West Africa (Akobundu 1981).

The warm and moist conditions prevalent in hydromorphic soils tend to reduce herbicide efficacy, but thiobencarb with propanil, MCPA with propanil, and oxidiazon with propanil have proved effective. Granular 2,4-D is a good and cheap herbicide that can be combined with good water control in irrigated rice fields. Use of the right herbicide applied at the right rate and time with a properly calibrated sprayer that has the correct nozzles is essential for good results with chemical control.

INTEGRATED METHODS

Development of integrated weed control practices is the goal of all weed-management strategies because no single method will control weeds in all rice ecologies. Integrated weed control combines cultural with biological methods, etc. One example is the stale-seedbed technique, which combines tillage with properly timed application of herbicides to destroy the first flush of weeds following tillage. The success of the technique depends on the quick germination of all weed seeds in the plot. Although Castin and Moody (1981) reported significantly reduced weed weight using the technique, they also noted a change in weed flora, which suggests a resurgence of weeds in future.

Another example of cultural and chemical control was tested by Tauro (1970 in De Datta 1979), who was able to reduce the time of rotary weeding in transplanted rice from 112 h/ha to 65 h/ha by use of an herbicide (Table 7).

Table 7. Efficacy of hand weeding, rotary weeding, and chemical weeding and combinations as weed control in transplanted IR8 rice (De Datta 1979).

Weed control[a]	Time to weed (h/ha)	Grain yield (t/ha)	Efficacy (kg rice/h work)
Hand weeding	202	4.9	17
Rotary weeding	115	4.1	22
Rotary weeding, then hand weeding	153	4.6	20
MCPA spray, then hand weeding	212	4.3	13
MCPA spray, then rotary weeding	65	4.3	42
Unweeded check		1.6	

[a]Weeding was done 20 and 40 days after seedlings were transplanted.

WEED RESEARCH PRIORITIES IN WETLAND

Weed management is an integral part of all comprehensive crop-protection and production activities, so the concepts, principles, and practices relating to weed science must be taken into consideration in plans for crop production. Any development of the wetlands must incorporate weed control. Without improvement in the weed-control practices, farmers in Africa will not benefit from the progress that has been made in other production inputs, such as improved varieties, use of fertilizer, and improved techniques of land preparation. To develop such management systems, scientists need a good knowledge of the biologic and physiologic characteristics of the weeds as well as how and when they interfere with the rice crop. At present, too little is known. Some priorities for research include:

- Manipulation of crop attributes to reduce losses caused by weeds;
- Identification of types, rates, and formulations of herbicides as well as application techniques that are attractive to small-scale farmers (for example, water-dispersible formulations in easy-to-use dispensing bottles that only need to be shaken before being used in the paddies); and
- Combinations of methods to produce integrated weed management that is environmentally safe and economically acceptable to a cross-section of farmers in the tropics.

DISCUSSION SUMMARY

How is sheath rot controlled?

Breeding for resistance, selecting varieties with good exsertion, adjusting planting date to avoid low temperatures during flowering (tropical highlands), and applying benlate and difolatan are all means to control sheath rot.

Is incidence of blast stress-related?

Results from controlled greenhouse experiments indicate that microclimate differences do not account for the difference in blast development between upland and flooded conditions.

What are the recent findings on the influence of silica on blast development?

Silica, or rather the silicification of cells, seems to hinder penetration by the pathogen but probably does not have any effect on the hypersensitive reaction under flooded conditions. Manganese is of more interest as a co-enzyme that seems to be involved in the hypersensitive reaction. Another approach to solving the blast problem is to breed or select for blast resistance in upland crops. Partial resistance can be accumulated when the crop is subsequently grown under flooded conditions.

What is the best method for screening for tolerance to iron toxicity?

The best method is probably to conduct screening under field conditions if one has a good knowledge of hydrologic and soil characteristics. Redox potential and ferrous ion should be monitored with collaboration from a soil scientist. A satisfactory laboratory screening method is yet to be developed.

At present, are the farmers in Africa ready to use herbicides on rainfed rice?

No. The use of herbicides on small rice farms is still at an experimental stage. Chemical weed control is a component of modern rice farming, and I believe researchers (in Africa at least) should give emphasis to weed control through cultural practices and biological means rather than chemical control.

CROPPING SYSTEMS

Present land use and cropping systems in Africa

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Abstract *In the time since chemical fertilizers and irrigation systems were first introduced, intensive rice growing has gained a foothold in Africa. For example, rice is being intensively grown in small-scale irrigated projects in Côte d'ivoire, Sierra Leone, Liberia, and Cameroon, and several projects are getting under way in Nigeria. The area under irrigated rice is likely to grow, but, in the meantime, most of the wetlands are underutilized, serving mainly as a source for forest products or being cultivated with yams and other crops that are moderately tolerant of wet conditions. Mangrove rice and rainfed lowland rice are also common in the wetlands.*

In subsaharan Africa, most of the wetlands are underutilized. Many of the large wetlands such as the deltas and floodplains in the humid, forested regions have never been cultivated, and the small wetlands, such as the inland valleys (or fadamas) in the subhumid regions, often have been used only for upland crops such as yams, sweet potatoes, and vegetables that are grown either during the dry season or on large mounds or raised beds during the rainy season. Their potential for use in intensive rice cultivation is only now gaining widespread attention, although the Asian rice species (*Oryza sativa* L.) was introduced to subsaharan Africa centuries ago (Carpenter 1978) and has been cultivated in the wetlands under rainfed conditions.

The indigenous rice species, *O. glaberrima* Steud, grows wild throughout the wetlands in the subhumid region and attests to the suitability of the environment for rice.

Many different terms have been devised to classify rice-growing environments, including those belonging to the wetlands (Garrity 1980). For subsaharan Africa, Moormann and van Breemen (1978)

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published a simple classification that has been debated but is still commonly used:

- Cultivation on lands with groundwater but no flooding (phreatic riceland). A considerable part of the water may be provided by rainfall. Cultivation of rice on this type of land is quite similar to upland or pluvial rice cultivation. The major difference is that crop losses due to drought are usually less severe.
- Cultivation on lands that are flooded, either naturally or artificially or both, during a considerable part of the growing season (fluxial riceland). Fluxial or flooded ricelands can be subdivided according to various criteria (Garrity 1984), with the conventional classification comprising irrigated, mangrove, deep-flooded, and floating rice.

This simple classification was found by the West Africa Rice Development Association (WARDA) to be usable in most cases, but not in all. Hence, in 1980, the association published a revised classification in which groundwater cultivation, with or without rains (phreatic riceland), was not counted as wetland cultivation. "Lowland cultivation" was subdivided into mangrove rice cultivation and freshwater cultivation with or without water control (WARDA 1980). Floating rice (deepwater rice) was classified as a special case of freshwater cultivation.

INTENSIVE RICE-BASED SYSTEMS

Although most rice cultivation on wetlands in subsaharan Africa is for subsistence, the total area is increasing. The use of improved methods of land preparation that include leveling, bunding, and irrigation is not yet common, but it has proved profitable and will probably expand (Shiawoya et al., elsewhere in this volume).

Rice cultivation on small inland valleys with good water control, which was introduced by the Chinese agricultural missions in the 1960s, has been successful in Côte d'ivoire, Sierra Leone, Liberia, and Cameroon and, according to WARDA (1980), has expanded considerably during the past decade.

To increase rice production in subsaharan Africa, intensified use of the wetlands is inevitable. The trend is already apparent. Before World War II, for instance, travelers in the northern part of Côte d'ivoire would have observed many uncultivated inland valleys or swamps, whereas at present most of the small and medium-sized valleys have been developed as ricelands. Some of the valleys have been developed with sophisticated systems of leveling, bunding, irrigation, and drainage to facilitate good water control. Small reservoirs have been built to provide year-round irrigation.

In Ndop plain, western Cameroon, an irrigated rice scheme has been maintained and operated mainly by farmers for more than 10 years.

In other words, intensive rice cultivation managed by local farmers has already become a reality in some parts of subsaharan Africa despite many technical and socioeconomic constraints; we believe it is bound to become more important and widespread.

Currently, however, other uses of the land are much more common; they include:

- Traditional gathering of forest products;
- Yam-based cropping;
- Dry-season vegetable production;
- Rainfed lowland rice; and
- Mangrove rice.

TRADITIONAL GATHERING OF FOREST PRODUCTS

In the humid regions, the wetlands are used mainly by local inhabitants as gathering grounds for forest products such as oil palm, raffia palm, medicinal plants, firewood, and building materials. For many reasons, these lands have never been cultivated, including the presence of waterborne diseases such as schistosomiasis and river blindness (onchocerciasis) and the lack of sufficient populations to exert pressure for land.

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Mounds are constructed at the end of the rainy season in southeastern Nigeria. The farmers almost exclusively use hoes for land preparation.

Attempts to reclaim these large wetlands would require careful planning with consideration given to the agricultural potential of the land, the ecologic consequences of developments, and socioeconomic implications (Hekstra 1983). There are three unused large wetland areas in the region, namely, the lower Niger delta, the Congo basin, and the upper White Nile swamps.

YAM-BASED CROPPING

Among the smaller wetlands, traditionally farmers have grown a range of upland crops that are moderately tolerant to wet conditions. In the drier regions, they plant the crops in the valley bottoms where natural flooding does not occur or occurs only during the peak of the rainy season. In the high-rainfall areas, they cultivate the wetlands found on the lower slopes of the valleys or on plateaus with an impermeable layer in the subsoil.

The use of wetlands for yam cultivation in subsaharan Africa dates back many centuries. In the subhumid regions of West Africa, water yam (*Dioscorea alata*) and sweet potato (*Ipomoea batata*) are planted on mounds in the valley bottoms, and sugarcane (*Saccharum officinarum*) is grown at the foot of the slopes of many small inland valleys or fadamas (Diehl 1982).

In the humid regions, white yam (*D. rotundata*) on large mounds

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Yam (supported by stakes) and egusi melon are a common combination on the mounds found in the wetlands of southeastern Nigeria.

or heaps is often seen in both small and medium-sized wetlands.

The large mounds are prepared manually with a special hoe at the end of the rainy season. The system is an effective, albeit labour-consuming, means of artificial drainage. It has been used extensively, for example, in the Abakaliki area in southeastern Nigeria and in the Lama Kara region of Togo.

Each mound is a microtoposequence from moderately well-drained at the apex to poorly drained (or flooded during the peak rainy season) at the lower edge. On each mound, a whole range of crops may be planted, according to their tolerance of high groundwater. Maize, beans, melons, pepper, and okra are commonly grown on the sides of the mounds (Bachmann and Winch 1979), with white yams being planted at the top and later supported by stakes.

As rice gained popularity, it also began to be planted between the mounds in places where deep flooding did not occur during the cropping season. More recently, however, the trend has been toward monoculture rice cultivation.

DRY-SEASON VEGETABLE PRODUCTION

Many inland valleys in the subhumid and semi-arid regions have traditionally been used for dry-season production of vegetable crops, including tomatoes, onions, and peppers, which are transported to

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Dry-season vegetable cropping is common in inland swamps in Sierra Leone and elsewhere in West Africa.

urban markets for sale. This is a common practice in northern Nigeria where the temperatures in the dry season are cool enough for cultivating such crops. Many of the wetlands in these areas are not used in the rainy season because they are either deeply flooded or situated in areas where rice has not been a traditional crop.

RAINFED LOWLAND RICE

A large part of the rice in subsaharan Africa is rainfed (Moormann and van Breemen 1978). For example, it is commonly grown in the uplands of Sierra Leone, Guinea, and Liberia where rainfall is substantial and evenly distributed. Rainfed rice cultivation on wetlands (or rainfed lowland rice) is also widespread in the small inland valleys throughout the region, particularly in Sierra Leone, Liberia, Guinea, Côte d'ivoire, and the central part of Nigeria (WARDA 1980; Ayotade and Fagade, elsewhere in this volume).

Rainfed lowland rice is generally grown in valleys in which some of the land is unflooded, some is occasionally flooded, and some is flooded during the major part of the cropping season. The differences in soil-water regime reflect either the topographic position of the land or the distance from the source of seepage or interflow. The extent of flooding, of course, also depends upon the stage in the rainy season: farmers generally adjust their date of rice planting (or transplanting) in various parts of the valley to avoid deep flooding during the early stage of growth.

Shifting cultivation is the common practice: the farmers treat the wetlands similarly to the upland areas, allowing the land to

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Rainfed lowland rice is transplanted on ridges in the Kaduna river floodplain, Nigeria.

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revert to bush or grass fallow after 1–2 seasons of rice cropping. The land is prepared manually into ridges or small heaps before flooding occurs, and rice is direct-seeded or transplanted on top of the ridges. In areas where farmers cultivate crops on both uplands and wetlands, rice in the valley bottoms is generally transplanted during the later part of the rainy season or after the harvest of most of the crops in the upland.

In the subhumid and semi-arid regions large wetlands that are subject to flooding are also used for rice cultivation — sometimes in a pattern of bush fallow rotated with rice but more frequently as permanent riceland with moderate use of nitrogen fertilizer. For example, on the floodplains along the Kaduna River and its tributaries in the central region of Nigeria, large patches are traditional rice fields. Farmers in this area grow a tall rice variety with abundant tillers. The variety was introduced from then British Guyana and was subsequently improved at the nearby rice research station at Badeggi.

MANGROVE RICE

Mangrove (estuarine or tidal) swamps are found at the mouth of major rivers in West Africa. These swamps are flat and poorly drained, with the depth of flooding being influenced by tidal water. The soils are mainly acid sulfate soils, which when saturated and reduced during the rainy season generally have a pH between 5 and 6. During the dry season, they become very acidic (pH < 3) because of the presence of sulfuric acid.

Mangrove rice cultivation was introduced to West Africa — to countries such as Sierra Leone and Senegal — probably little over a hundred years ago. Several thousand hectares of such swamps near Rokupr in Sierra Leone have long been used by farmers for rice cultivation. The area has fertile soils and timely freshwater flooding during the rainy season. Average rice yields from farmers' fields in these swamps are 2–3 t/ha without fertilizer use (C. Dixon, personal communication). However, the development of unused mangrove swamps for rice cultivation is a long-term endeavour that must be based on hydrologic, soil, and socioeconomic surveys.

Rice-based systems in subtropical China

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Abstract *Double and triple cropping of rice has progressively increased in China. In some areas, rice is rotated with upland crops or green manure to improve the soil structure and fertility. Zhejiang Province is particularly well suited to rice production, and about 80% of the riceland in this province is irrigated. Fertilizer is applied to the rice at a rate of 400 kg N/ha, about 50% of which is organic manure. Most of the crop is established in nurseries and transplanted later, but research is under way to improve yields from direct-seeded rice, as the costs of labour are high for transplanting. Current practices to increase yields and income without increasing land under cultivation include fish farming during or after the rice as well as introduction of upland crops that are in limited supply.*

In China, the area of yearly rice production is about 33 Mha. The rice (unhusked) yield in 1983 was 168.87 Mt, about 3.5 times the yield in 1949. The production areas are concentrated in the subtropic region, with 57% of the yield coming from the middle and lower basin of Changjiang (Yangtze) River. Rice production in this region dates back 7000 years: carbonized rice, cultivating tools, and a rice-processing instrument were found in the Hemudu and Luojiajiao ruins on the plains of northern Zhejiang Province. In this region, the annual mean temperature is 14-16.5°C, with 230-265 frost-free days annually and about 750-1300 mm rainfall.

Zhejiang Province has been a leader in developing multiple cropping systems incorporating rice. The results have been steady increases in per-hectare and total yields of grain (Fig. 1). The stability of the yields has also increased, although natural disasters have caused some poor harvests.

Double cropping of rice can be traced to more than 900 years ago in the lower basin of Changjiang River. Today, three crops yearly (including a winter upland crop such as barley, rapeseed, broad

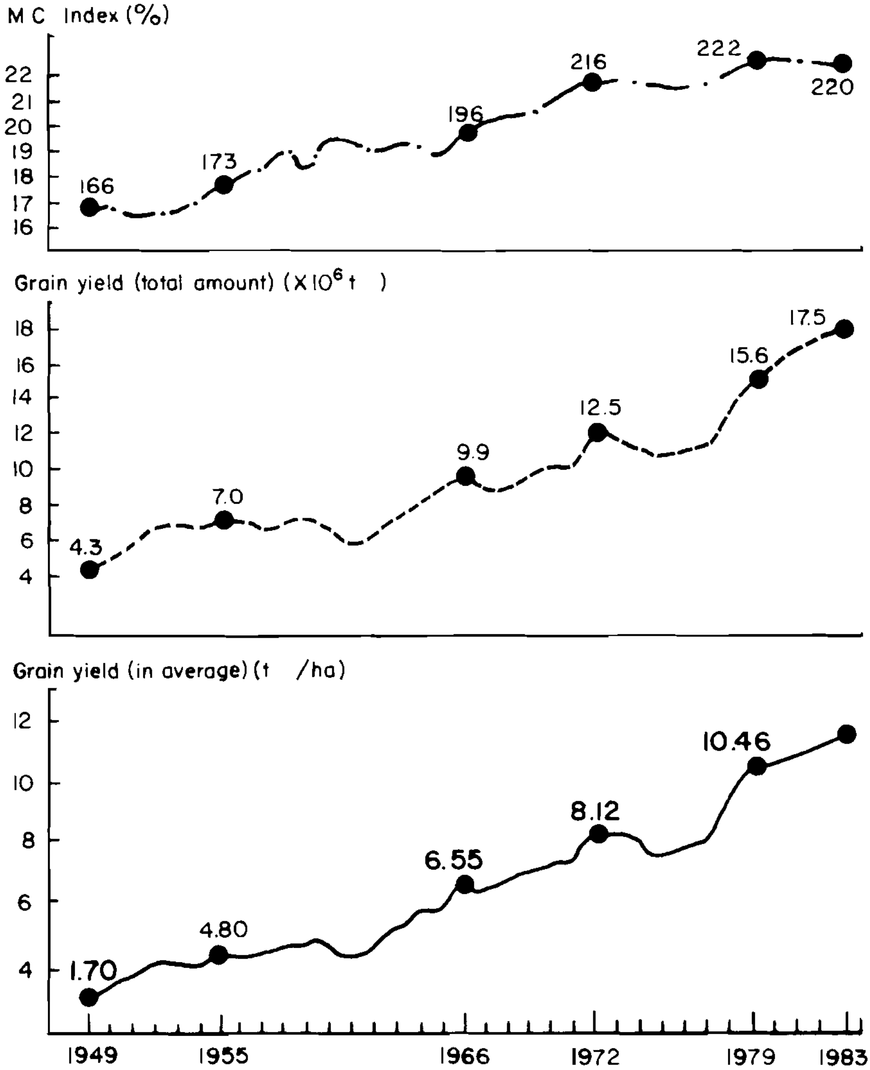

Fig. 1. The grain yield has steadily increased in Zhejiang Province over the last 30 years because of the increase in multiple cropping (MC).

bean, or legumes for green manure) and double cropping of rice are widespread in the middle subtropical region. In the northern subtropical region, winter crops and rice as a monocrop are the main system. Other systems exist as a reflection of different natural and economic conditions (Fig. 2).

In systems of triple cropping, the winter crops are planted after the second crop of rice has been harvested (Fig. 3). This pattern suits regions in the middle and southern subtropics where the climate is warm, the labourers are plentiful, and the soil is fertile. Some constraints do exist: rural labourers have increasingly moved into rural and urban industries and are becoming harder to find for farming activities during the busy periods. Medium and small farming machinery for tillage, cultivation and irrigation has been available for a long time, as has mechanized and semimechanized harvesting, threshing, and transportation. Seedling pulling and transplanting have not yet been mechanized, and they represent a constraint to many farmers in the region. Consequently, research on direct seeding of early maturing and high-yielding varieties is under way.

Costs of inputs have risen faster than income, but farmers in the region will maintain the multiple cropping index as a means to help meet the country's growing food requirements and to supplement their incomes. Some farmers have replaced the first crop of rice with melon or sweet corn because of the cash returns possible from these combinations.

In the northern subtropical region, where the frost-free period is shorter and labourers are fewer than in the south, a single crop of rice is followed by an upland crop like wheat, made possible by good techniques of soil management and fertilization.

Since the 1950s, improvements in such techniques have not only allowed farmers to grow two crops instead of one but have increased

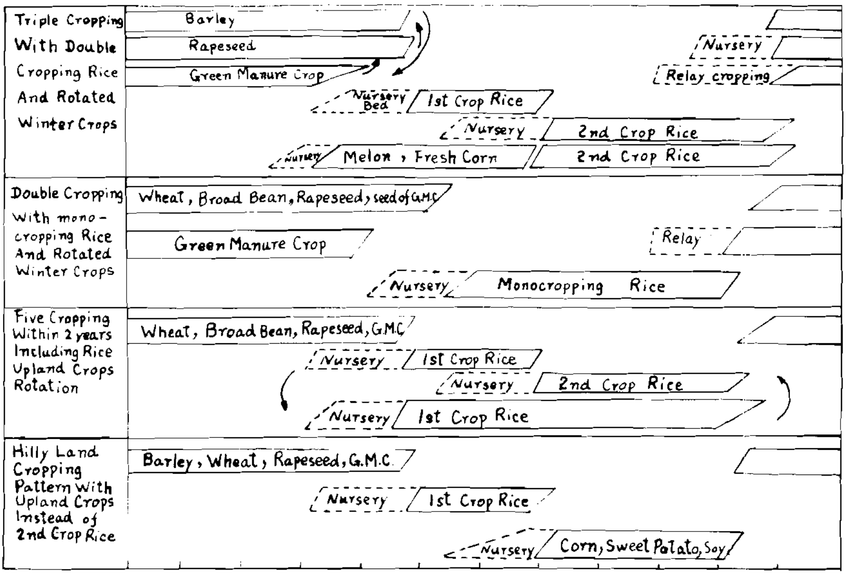

Fig. 2. Schematic representation of different rice-based cropping patterns in China.

yields of rice and, later, wheat. A recent addition to the rice-based cropping systems is raising fish in the paddy fields either instead of the second crop of rice after the first crop of rice has been harvested or during two rice crops. The latter has proved to have some ecologic benefits, because it reduces the requirements for pesticide. The long-term effects of this system are not yet known and are being closely monitored, especially in areas where the water table is high. Some concern has been voiced that if the quantity and the distribution of fish raising are not carefully controlled, the water table in the area will be raised permanently and lead to unfavourable physical and chemical properties in the soil.

In areas where the paddy fields are well drained — for example, alluvial soils along rivers and streams — double cropping of rice is rotated the next season with upland cash crops such as cotton, sugarcane, etc. The upland crops are chosen to maximize soil fertility and to reduce the plant diseases and insect pests as well as the weeds. The farmers' net income from this pattern is usually higher than from continuous rice cropping.

Another pattern used is winter crops and early-to-medium maturing rice as the first crop when rain is plentiful and autumn upland crops instead of a second crop of rice. This pattern fits the climate in hilly and mountainous regions where drought occurs in autumn and rain in spring and summer. Sometimes, one can find belt-like mixtures in which crops with different characters (high or dwarf; nitrogen saving and nitrogen consuming, etc.) are planted in the same plot in 2-m wide strips and are rotated with each other.

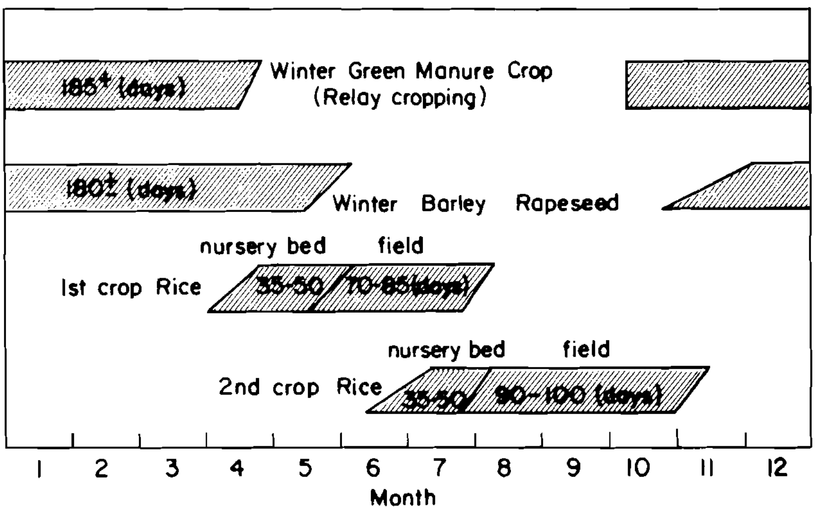

Fig. 3. Growth of crops.

A "mole plow", pulled by cable, is used to dig holes for midsummer drainage of paddy fields in China.

FIELD PREPARATIONS

Rice-based multiple cropping systems have gained in popularity in most regions of China. The success of triple cropping in the middle subtropical region is a reflection largely of good water management.

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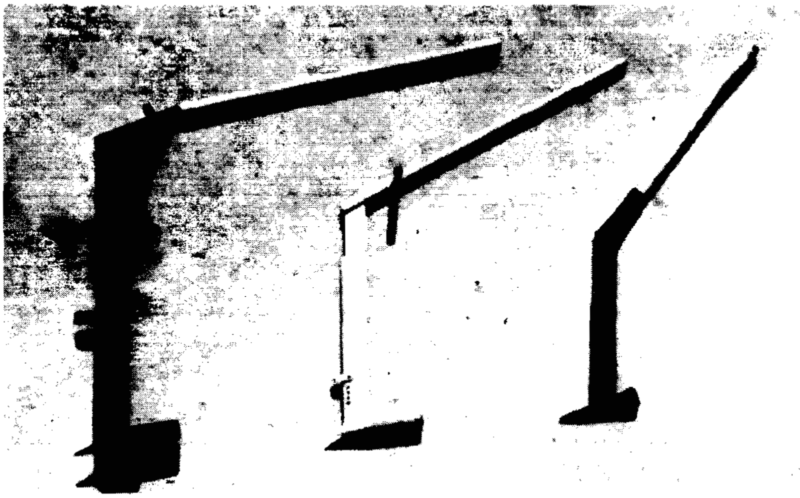
Three holes dug by mole plow in a paddy field in China.

More than 80% of fields in Zhejiang Province are now irrigated and drained regularly. The introduction of water control measures opened the way for upland crops. The fields were measured, the land was leveled, and irrigation and drainage systems were installed. In areas where flooding was common, canals and ditches were dug to reduce the levels of the inland rivers. The drainage system included open ditches and tunnels; the holes were dug by mole plows, which were towed by walking tractors or electrically driven machines.

SOIL MANAGEMENT

This system of water management is supplemented by intensive fertilization. To obtain yields of grain of 10 t/ha, farmers apply about



Three types of fittings for mole plows.

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400 kg N/ha yearly, about 50% of which is organic manure from swine, legume crops, etc. Part of the crop stalks are also returned to the field and mud is dug from the riverbeds to be added to the paddy fields.

At one time, *Azolla imbracata* was cultivated as fertilizer but has now been replaced by *A. filiculoides*, which has better cold tolerance and is highly productive. Also the sporocarp is easy to use in reproduction. Aquatic plants such as water peanut (*Alternanthera philicaloides*), water lettuce (*Pistia stratiotes*), and water hyacinth (*Eichhornia rassipes*) are cultivated on the river surface and later applied as fertilizer.

To collect farmyard manure, farmers dig a round or square pool. Straws, livestock manure, green manure, and small amounts of wild grass are gathered and thrown into the pool, mixed with riverbed or pondbed mud and allowed to decompose.

Crop rotations and intercrops are chosen to benefit the soil. Nitrogen-fixing varieties are a major component. Winter crops are mainly green manure (commonly *Astragalus sinicus*), wheat, barley, rapeseed, or broad beans. Such crops have been shown to reduce the bulk density of the soil and increase porosity. This characteristic is particularly important in areas where land preparation is mechanized. With time, the rolling-harrowing operation performed in shallow water with a "walking tractor" leads to unfavourable soil changes — shallow topsoil, puddling, and the formation of a gley horizon just below plowed layers. Introducing a winter crop has improved the conditions markedly. In one trial, in plots cropped solely with rice, large pores occupied about 11% of the land space and

Pools to collect organic manure are dug at the corner of paddies.

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constituted 22% of the total porosity; comparable figures from plots where green manure, barley, or wheat was grown as a third crop were 6% and 13%. As expected, soil nitrogen was increased after green manure and rapeseed but reduced after barley. Complementing triple cropping is systemized drainage, tillage, and sun drying of the upturned soil or a no-tillage system that incorporates stubble clearing.

VARIETIES SELECTED FOR HIGH YIELD AND MATURATION

In southern Zhejiang, the first crop of rice has better growing conditions than the second crop so semidwarf varieties, Xien (*Oryza*

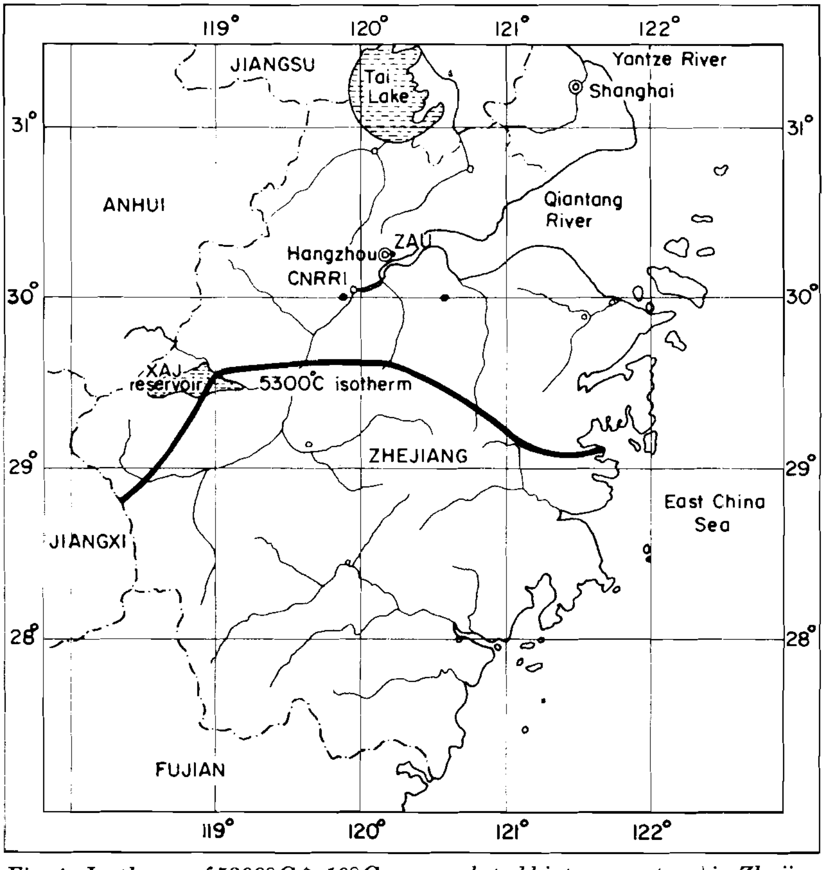


Fig. 4. Isotherm of 5300°C (>10°C accumulated biotemperature) in Zhejiang Province.

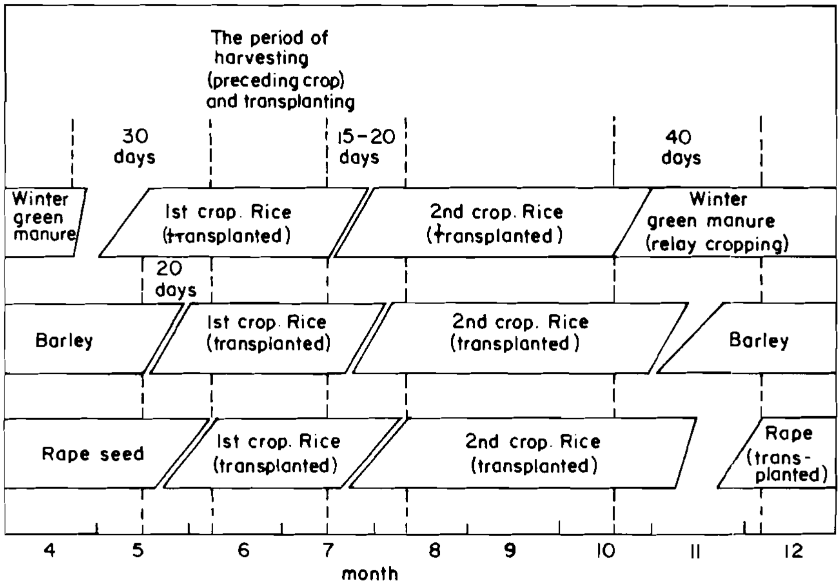


Fig. 5. Use of different varieties of rice and upland crops to extend the period of harvesting and transplanting.

sativa sinica), are planted to ensure yields not lower than 6 t/ha. In the second crop, 36% of the total paddy fields of the province are planted to hybrid rice. In the North, varieties of Gen (*O. sativa indica*), which tolerate the cold, are planted (Fig. 4).

Each production unit chooses varieties, planting, and

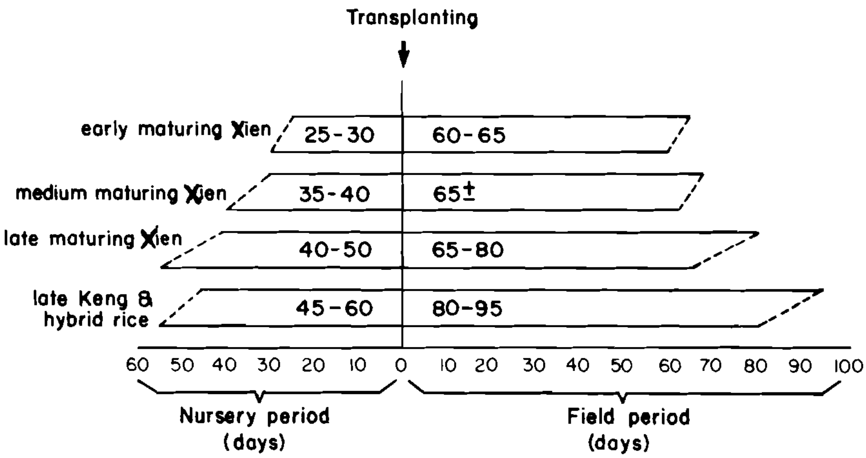
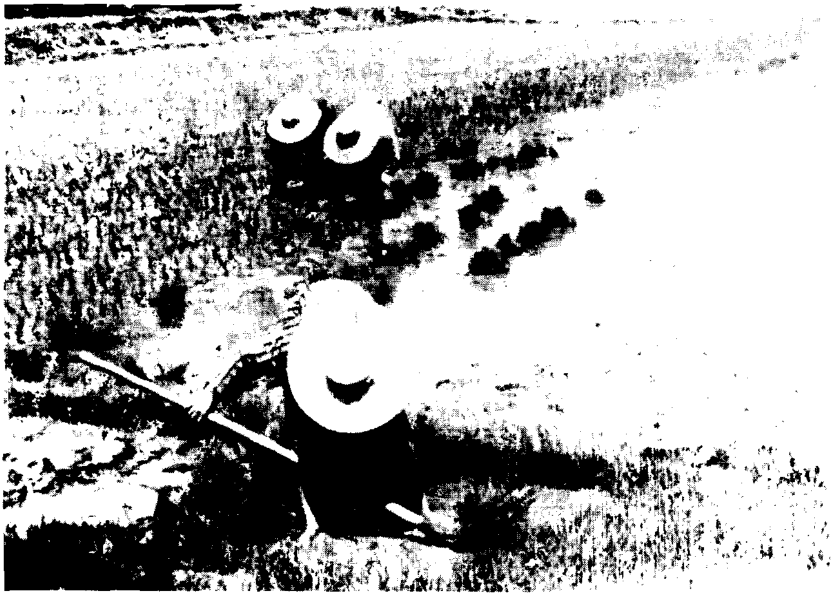


Fig. 6. Nursery periods required by different varieties of rice.



Transplanting seedlings in Zhejiang Province.

harvesting time to make the best use of the land (Fig. 5) given the cropping system. In multiple cropping, the most serious constraint at present is the limited farming seasons, the effects of which have been somewhat offset by seedling nurseries.

Nurseries for seedlings incorporate both the early maturing varieties and the higher yielding late-maturing varieties. The time in the nursery is extended to reflect the maturation periods of the crop (Fig. 6). Seeds are planted at close spacings and intensively managed until the plants are established. When the seedlings are about 80 cm tall, they are transplanted to a nursery field that has been plowed, harrowed, leveled, and fertilized. Here they remain for up to 50 days before being transplanted to the paddies. This approach has resulted in 10% increases in yield.

Management of the crop in the field corresponds with changes in the colour of the leaves, which reflect physiologic and ecologic conditions (Fig. 7).

Photoperiod-sensitive rice varieties such as Keng (*O. sativa sinica*) turn from dark green to yellowish green at the end of the active tillering stage, again at panicle initiation, and a final time at the booting to heading stage. After the third change, the upper leaves are complete and new leaves grow slowly as the carbohydrates begin to be concentrated in the grain. Faster growing varieties exhibit

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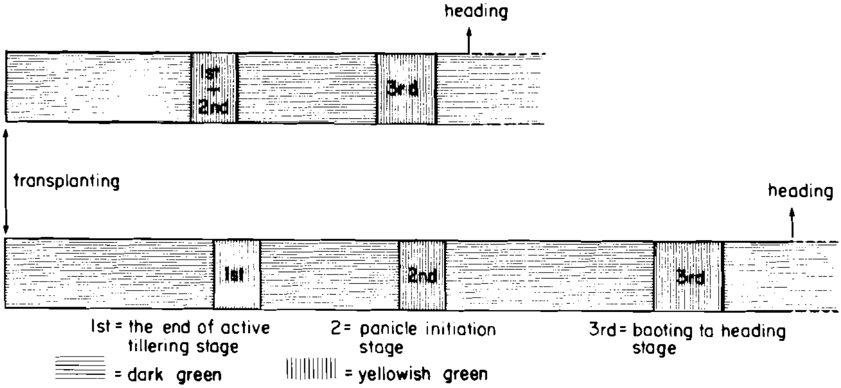

Fig. 7. The leaves change from dark to yellowish green as a reflection of physiologic landmarks.

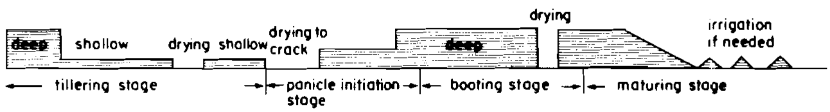

Fig. 8. Schematic representation of irrigation system for paddy fields in China.

colour changes only twice — during panicle initiation and heading.

The field is fertilized before the plants are transplanted; manure is added at the beginning of the tillering stage and again when the panicles are initiated. A top dressing is sometimes applied with care at the heading stage.

Water management, also, is closely linked with the physiologic changes of the crop (Fig. 8). At the end of the tillering stage, the paddy is allowed to dry until cracks appear on the ground; in low, wet fields a similar procedure is undertaken just before the heading stage.

CONCLUSIONS

Rice-based cropping systems are one means to manage, regulate, and control the agroecosystem. When integrated with methods of maximizing the efficiency of rural energy use, the cropping systems can be developed and improved. Cultural practices used in rice production are continually being refined, as farming systems are a major focus of practical research in the country. The cropping system is the core of every farming system and it determines the soil and water management, which must be integrated with methods of fertilization, disease and insect control, weed control, planting, spacing, and transplanting. As well, the structure and function of cropping systems can be profoundly influenced by the development of animal husbandry and a processing industry. Each activity represents a multiplicity of possibilities that can be tested together and alone in efforts to make full use of the environment. The goal is to fine-tune a stable, sustainable, and dynamic system.

Improved water control and crop protection in double-rice cropping: a system in Malaysia

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Abstract *The major causes of instability of yield in double cropping of rice in the Muda area of Malaysia during the early 1980s were the insufficient supply of irrigation water and the occurrence of rice tungro disease. The latter was a result of year-round cultivation with rice and could easily be remedied by the introduction of a short (about a month) fallow in the whole area during the dry season. The shortage of irrigation water could also be alleviated, although not quite as easily, with changes that conserve water such as shortening the period when the entire area was being irrigated. By sequential irrigation of the plots and by watering only the nursery before the seedlings have been transplanted, one could save more than enough water to maintain the system at high yields.*

In recent years, double cropping of rice has been rapidly spreading in Southeast Asia with the development of water resources and improvement of irrigation facilities. However, yields are extremely unstable and stagnant because of damage by rice tungro disease and the brown planthopper (BPH), *Nilaparvata lugens* (Stal). As such problems are likely to jeopardize the practice of double cropping in these areas, the Tropical Agriculture Research Centre of Japan has been carrying out a cooperative research project with the Muda Agricultural Development Authority since 1978 to establish a system that will produce consistently high yields of rice in the Muda area.

In this report, the results of this cooperative project are presented. The principles may prove useful for farmers in the flat wetlands of tropical Africa.

The Muda area, the largest paddy area in Malaysia, is a flat coastal plain of about 95 000 ha. Most of the soils are clays — ill-

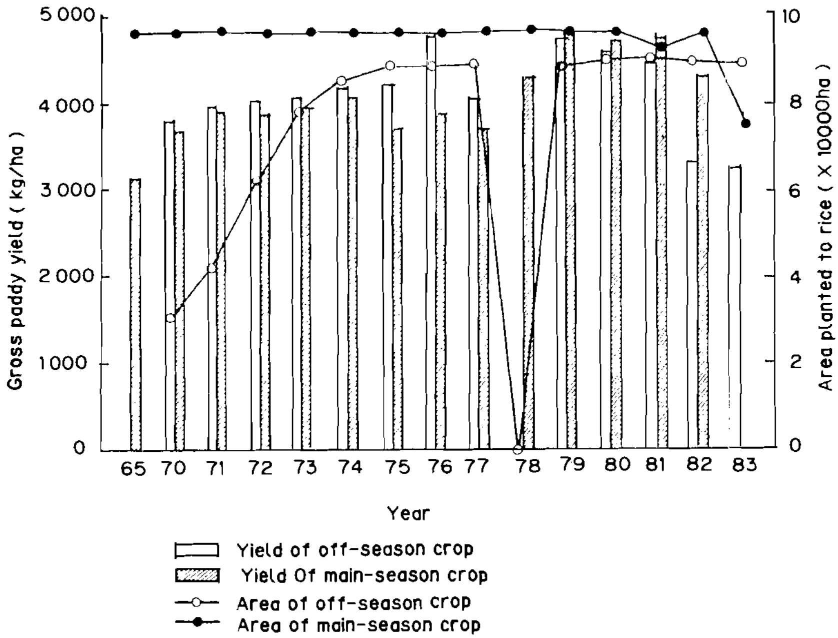

Fig. 1. Area and yield of plots continuously cropped with rice in Muda, Malaysia.

drained, blackish, and heavy. Derived from marine alluvium, they have a low bearing capacity under submerged conditions. The average annual precipitation amounts to about 2200 mm, falling mainly from April to November with two peaks — one in May and one in September-October. There is a distinct dry period from January to February.

Double cropping of rice was initiated in 1970 on 31.9% of the whole Muda area. The area rapidly increased to 92.5% of the total by 1975 and since then has remained relatively constant. At the beginning of double cropping, the cropping season was scheduled to extend from February to July for the off-season crop (first crop). However, cropping began to be delayed as the supply of irrigation water was insufficient and slow to arrive. Also, labour was in short supply and the farmers didn't understand the reasons for the scheduled cropping. The off-season crop in 1978 was canceled (Fig. 1) because of severe drought and lack of water.

Average yield of both off- and main-season crops had been about 3.7 t/ha (gross paddy basis) initially with slightly higher yields obtained in the off-season crop. The yields increased gradually every year until 1974. Thereafter, with the spread of double cropping to the whole area, the yields dropped (mainly because of water shortages).

Table 1. Average water balance in irrigated plots, Muda area, Malaysia, 1979–81.

	Irrigation time (days)	Supply of water (mm)[a]	Consumption (mm)			Water requirement (mm/day)
			Remainder	Evapotranspiration	Outflow	
OFF SEASON						
Pretransplanting	73	976	(384)	179	396	401
Posttransplanting	107	921	(578)	-80	596	405
MAIN SEASON						
Pretransplanting	74	744	(435)	76	370	298
Posttransplanting	99	867	(205)	-104	700	271

[a]Figures in parentheses indicate the water supplied by rainfall.

From 1979 to 1981, high yields were obtained (Fig. 1) with increased application of fertilizer (83 kg N/ha, 30 kg P_2O_5/ha, 20 kg K/ha), which was made available from 1979 onward by the government at no cost to the farmers. During the off season of 1981, however, rice tungro disease was first detected in the southern part of the area, and it spread over the entire area in the off season of 1982. Despite the use of high-yielding varieties and fertilizers, the yields of off-season crops in 1982 and 1983 dropped to the levels obtained before double cropping had been introduced.

WATER SHORTAGE

The shortage of irrigation water was a reflection of the instability of the sources; 46% of the requirement came from fluctuating rainfall (Table 1). Also, the use of the water was inefficient because of the flat

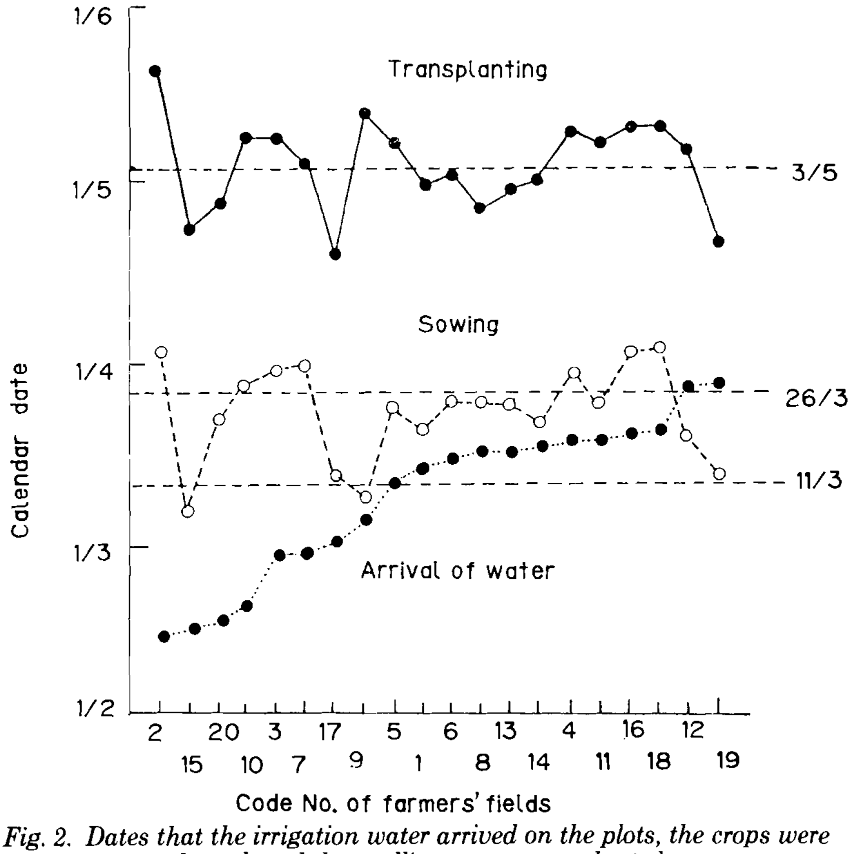

Fig. 2. Dates that the irrigation water arrived on the plots, the crops were planted, and the seedlings were transplanted.

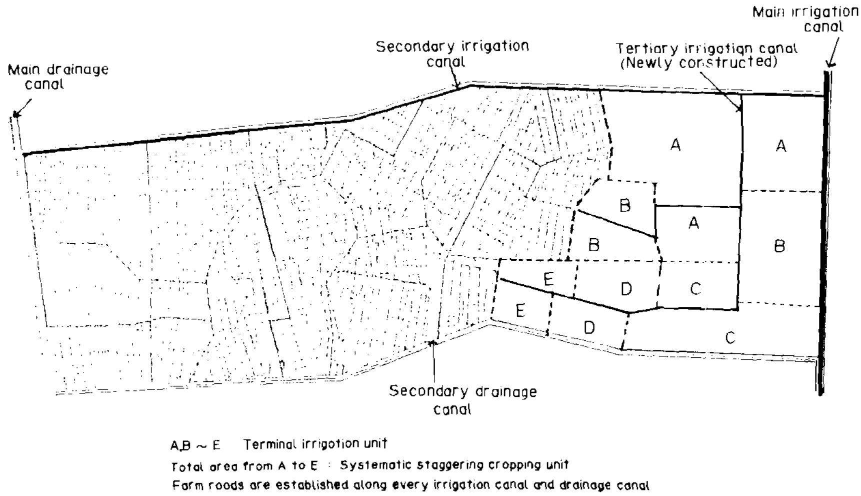

Fig. 3. Systematic staggering of cropping and irrigation to conserve water.

land (1/5000 to 1/10 000 inclination) and insufficient numbers of canals. Other contributing factors were labour shortage and little understanding among the farmers about efficient use of water.

The irrigation period was remarkably long (353 days), and shortening it was seen as one way to alleviate the water shortage. The irrigation period before transplanting (presaturation period) was nearly 2.5 months in both cropping seasons, although field experiments indicated that 40 days was sufficient. Moreover, the entire plots were being soaked during this time, even though the water was being used only in the nurseries.

Such a long presaturation period was brought about by late transplanting done all at one time after irrigation water had been supplied to the whole area (Fig. 2). The reasons for simultaneous, late transplanting were to avoid the risk of damage caused by rats and birds and the risk of drought injury before the rains. Also the agricultural machinery had to be moved across the fields located at the periphery to reach the inner fields of the irrigation block because of the lack of farm roads.

One way to solve the problems would be to build roads along irrigation canals and to construct an additional canal that could support systematic, staggered cropping (Fig. 3). The irrigation block would be divided into three or four cropping units, each consisting of five irrigation units (A to E) each of which could be soaked within 1 week. Irrigation would be staggered such that water is delivered to all the A units first, then all the B units, etc., until the 5th week when the E units would be watered. This system would shorten the presaturation period by nearly 25%.

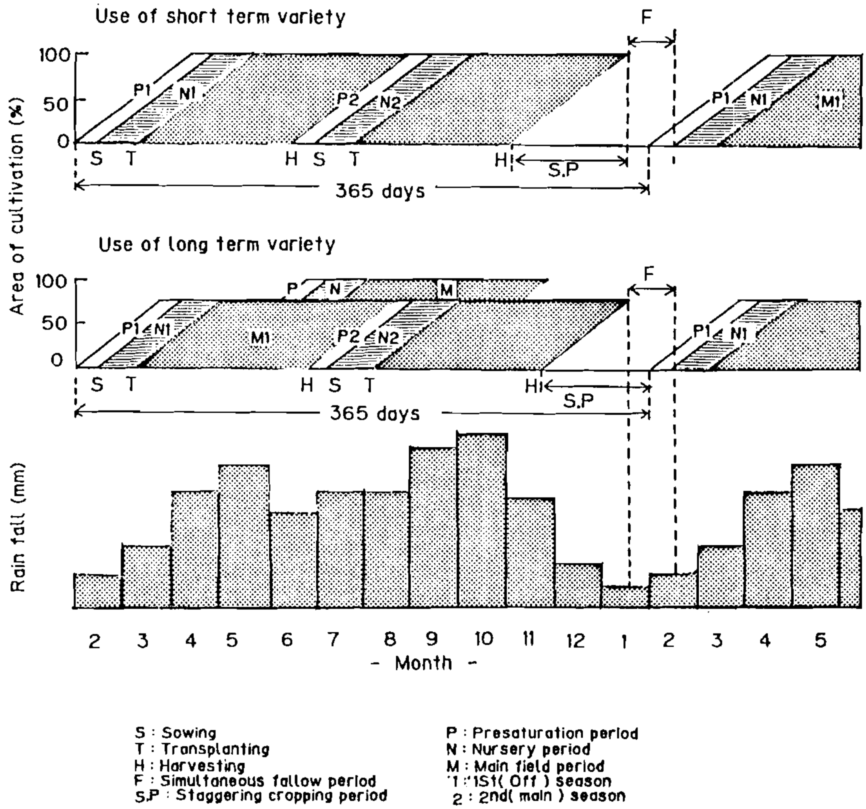

Fig. 4. Schematic of the proposed system for double cropping of rice in Muda, Malaysia.

Introducing independent irrigation of the nurseries would cut water consumption by about 58%. Small ditches could by constructed from the main canals to the nurseries or the nurseries — run by the community or by commercial operations — could be placed near the canals.

The irrigation period to the main field after transplanting could be shortened by the introduction of early maturing varieties. A suitable variety is one that matures within 125 days of cultivation, whereas the varieties currently being used take 140 days to mature.

RICE TUNGRO DISEASE

Rice tungro disease is a virus mainly transmitted by the green leafhopper *Nephotettix virescens* Distant. Although the mechanism by which the disease becomes established has not yet been clarified, its occurrence is closely related to year-round cultivation of rice and heavy application of fertilizer. At present, varieties resistant to the virus, and insecticides to control the vector are being used. However, these measures are accompanied by the risks that new biotypes will evolve, that the insects will become resistant to the insecticides, that there will be resurgence of insects in an area subjected to chemical control, and that the area will become irreversibly polluted by the extensive use of chemicals possessing high residual activity.

A simple method of control consists of discontinuing cultivation for 1 month during the dry season over the whole Muda area to remove the insect's host. The green leafhopper cannot survive longer than 10 days when deprived of host plants, but at least 1 month is needed to kill all the host plants, including rice stubbles, ratoons, volunteer rice plants, and weeds comprising other *Oryza* species in the area.

THE SYSTEM

Based on the suggested improvements in irrigation and ecologic control of rice tungro disease, I propose a new system of rice double cropping that incorporates a 1-month fallow between successive years (Fig. 4).

The crops would be staggered over at least 75 days based on the current irrigation capacity of the area. Consequently the double-cropping period for each plot would be 275 days — 365 − 15 (half the fallow) − 75 days. Any variety that matured within 125 days of cultivation (with manual transplanting or direct seeding in submerged soils) would be suitable.

At present, tertiary irrigation canals and farm roads that will make the whole system possible are being constructed in the Muda area, and, since 1984, the fields have been left fallow for 1 month during the dry season.

Besides saving water and controlling rice tungro disease, this system is expected:

- To make effective use of agricultural labour and machinery;
- To facilitate land preparation, with mechanized operations being undertaken during the fallow period when the bearing capacity of the soils is suitable; and
- To effect the increases in yield that have been shown to accompany periodic drying of the soils.

DISCUSSION SUMMARY

What proportion of wetlands in subsaharan Africa is considered underutilized?

A large proportion of the region's wetland is underused in terms of cultivation of rice and other food crops. But most of the wetlands are used in one way or other. For example, in the savanna regions, the wetlands serve as grazing grounds for the Fulani's cattle during the dry season. In the forest zone, wetlands are used for producing oil palm, raffia palm, wood, and native herbs.

Are vector-borne diseases serious problems in wetland development?

River blindness (onchocerciasis) and schistosomiasis are common health problems in wetland areas. Asian experiences indicate that they can be controlled once the wetlands are developed for more intensive use.

In double cropping in Malaysia, the yield (4 t/ha) of off-season rice is about 1 t/ha higher than the yield from the main season. Any explanation?

Soil drying before off-season rice was found to be the main reason for yield increases. The difference in daily solar radiation between the off season (1256-1590 J/cm^2) and the main season (1256-1465 J/cm^2) does not seem to be significant.

What are the socioeconomic considerations relating to the intensive rice-based cropping systems in China?

The farming systems as practiced in China are labour intensive. The government encourages and assists many aspects of agricultural activities and village industries to minimize migration of the rural population to the cities.

The Chinese system is indeed intensive, with only a few days between crops. How is the soil prepared for the upland crops after the second crops of wetland rice?

Mainly through drainage. Deep drains are dug around and within fields. Tile and plastic drains are also used.

MECHANIZATION

Appropriate mechanization for rice cultivation in Africa

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Abstract *In areas where mechanical tools and implements have been designed or adapted, the driving force for their development has been a shortage of labour where the shortage is primarily a reflection of other opportunities for the labour force. The developments have been fastest in countries where the opportunities have been both within and outside agriculture; Japan, Taiwan, and South Korea are good examples. However, mechanization proceeds even when the increased opportunities are primarily within the agricultural sector. For example, experience all over Asia has shown that the introduction of irrigation systems, high-yielding varieties of rice, and fertilizer use makes possible intensified cultivation and is accompanied by increases in production and labour requirements that force mechanization. In Africa, the opportunities for increased production within the agricultural sector are enormous, given the area of wetlands that are currently underutilized. Labour shortages, particularly for land preparation and weed control, are common and are one reason that the potential is not being realized. However, in general, African farmers do not have access to the means, such as training and an infrastructure for operation and repair of equipment, that have been available in Asia. A few large projects in Africa may be able to import equipment, but the smallholders who produce most of the food on the continent are more isolated than their counterparts in Asia. Whether concerted efforts in cooperation by national, regional, and international agencies to share, test, and adapt the techniques for mechanization can engender the massive increases in productivity and distribution that are necessary to feed the population is uncertain. A few designs and tools from the developing countries in Asia may prove to be adaptable to the conditions (socioeconomic and physical) found in Africa.*

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Agricultural mechanization refers to the use of hand tools, animal-drawn implements, or motorized equipment to carry out farming operations. Like other technologies for developing countries, appropriate forms of mechanization mean technically and economically feasible as well as socially acceptable (avoiding harmful labour displacement) tools that can be used within the prevailing infrastructure for land development, irrigation, credit, spare parts and repair, etc. Machines must be introduced selectively, that is, in selected regions — regions facing constraints for the development of improved, intensive farming systems (e.g., seasonal labour shortage, timeliness of operations, etc.) — and for selected operations — operations that constitute bottlenecks to the introduction of improved farming systems.

Schumacher (1974) described the general impossibility of directly transferring technologies from industrialized to developing countries: "The technologies and equipment designed for and introduced in the industrialized countries do not fit in conditions of poverty, because they presuppose the availability of ample capital resources and depend on the existence of an elaborate infrastructure."

Both in Asia and in Africa, however, there are a number of large-scale rice-growing projects for which Western types of farm equipment may constitute the only option. Under these conditions moderate to large tractors (with their related implements) and combine-harvesters are appropriate in the sense that no other, less-sophisticated types of farm equipment are available. Such farm equipment can be provided only through import (or at best gradual local assembling).

In general, however, rice is grown by smallholders using human and animal power sources. Mechanical power is introduced to supplement these traditional power sources where shortages of labour are seasonal, particularly for tasks such as land preparation. I believe the experience in Asia clearly shows trends in development that force the introduction of mechanization in rice production: wherever improvements have meant shortages of labour, mechanization has grown up spontaneously. The trends are clear in both the industrialized and the developing countries.

For example, the introduction of irrigation and high-yielding varieties of rice with fertilizers has almost universally been associated with seasonal labour shortages and is so closely tied to the push for supplementary mechanical power that the effects stand out, even though developments in sectors other than agriculture contribute to the shortages of labour that demand mechanization.

In other words, the move toward mechanical cultivation, harvesting, and processing is most rapid in countries where the labour force has options outside agriculture, but it occurs wherever production increases substantially. What's more is that the use of mechanical power fuels further increases in production.

Irrigation makes possible double and even triple cropping during a year so that labour requirements and production are increased beyond the capacity of smallholders; likewise, the increases in production made possible by wide adoption of high-yielding varieties and fertilizers have forced mechanization of harvesting and postharvesting techniques to prevent crop losses.

The equipment that has emerged represents designs that were invented, adapted, or improved in the countries to fit local conditions, including the cultural and socioeconomic milieu. Nowhere has mechanization preceded production increases or shortages in labour.

A look at the progression of the developments of machine building for smallholders producing rice in Asia provides some insights about requirements and forms of agricultural mechanization.

Japan exemplifies the technically advanced cultivation of rice; in the years between 1960 and 1975, the area under rice increased from 6.1 Mha to 6.8 Mha while the numbers of people involved in

Table 1. Changes in energy, sources of power, and income for rice cultivation: the move toward mechanization in Japan, Taiwan, and South Korea.

	Japan		Taiwan		South Korea	
	1960	1975	1975	1981	1984	Plans, 1987
Cultivated area (Mha)	6.1	6.8	na	0.9	13.8	13.8
Farmholdings (× 10^6)	6.1	5.3	na	0.9	15.3	na
Ave. size (ha)	1.0	1.1	na	1.1	0.9	na
Farm labour						
(% full time)	34.0	12.0	na	na	na	na
(workers/ha)	2.4	0.9	na	2.0	2.0	na
(h/ha)	1700.0	800.0	na	na	na	na
Draft animals ('000s)	650	<100	196	78	na	na
Machinery ('000s)						
Power tillers	750	3100	48	102	422	525
4-wheel tractors	—	720	—	1	6	35
2-wheel tractors	na	3200	na	102	na	na
Power threshers	2640	3300	135	na	254	220
Combine harvesters	—	1930	2	19	24	120
Machine costs (% of total production)	9	22	na	na	na	na
Income/holding[a]	410	3415	554	1350	na	na

[a]The Japanese figures are yen: CPY '000s, whereas the figures for Taiwan are an index with 1960 being equal to 100; na = not available.

agriculture dropped to about half — from 14.5 million to 7.9 million — and the number of draft animals dropped to less than a sixth of the former amount. At the same time, yields increased from 4.0 t/ha to 4.8 t/ha. The capacity to increase production and the area under production came solely from mechanization as labour began to move into industrial activities. The costs of machinery as a percentage of total production costs rose from 10 to 22, and the number of power tillers went from 750 000 to 3.1 million, power threshers from 2.6 million to 3.3 million, and combine harvesters and 4-wheel tractors from nil in 1960 to 1.9 million and 720 000 respectively in 1975.

The picture in Taiwan in the 1970s was similar, and South Korea is now moving in the same direction (Table 1). In these countries, the industrial and technical sectors need personnel; therefore, the labour force is able to demand higher wages, which, despite increases in food prices, cannot be sustained in the agricultural sector.

The effects of opportunities outside the agricultural sector tend to overshadow the effects of such innovations as irrigation; however, yields of rice in Japan where 98% of the holdings are irrigated are now 6 t/ha and in Taiwan and Korea where 80% of the paddy fields are irrigated, the yields are more than 4 t/ha.

Elsewhere in Asia, the proportion of irrigated fields is generally much lower as are yields of rice. For example, Kampuchea,

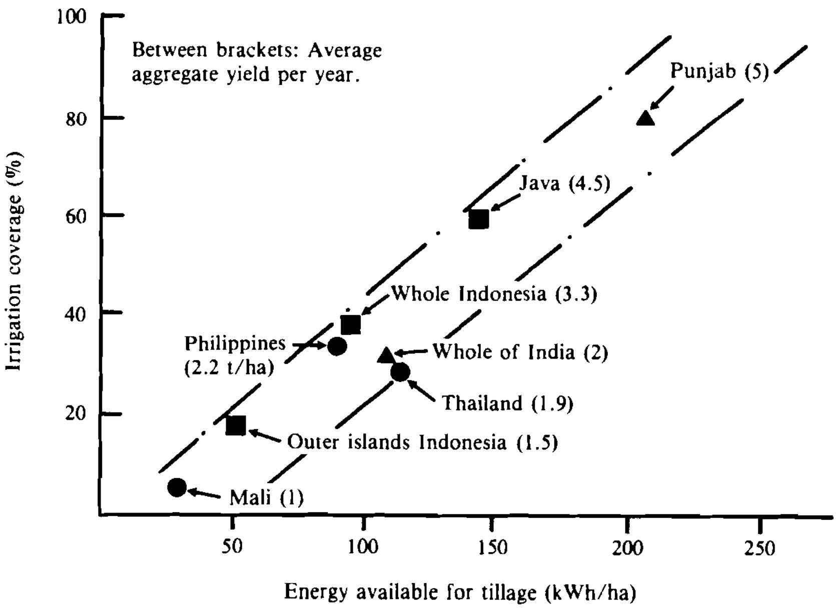


Fig. 1. Energy available per hectare as a function of irrigation in selected countries of Asia.

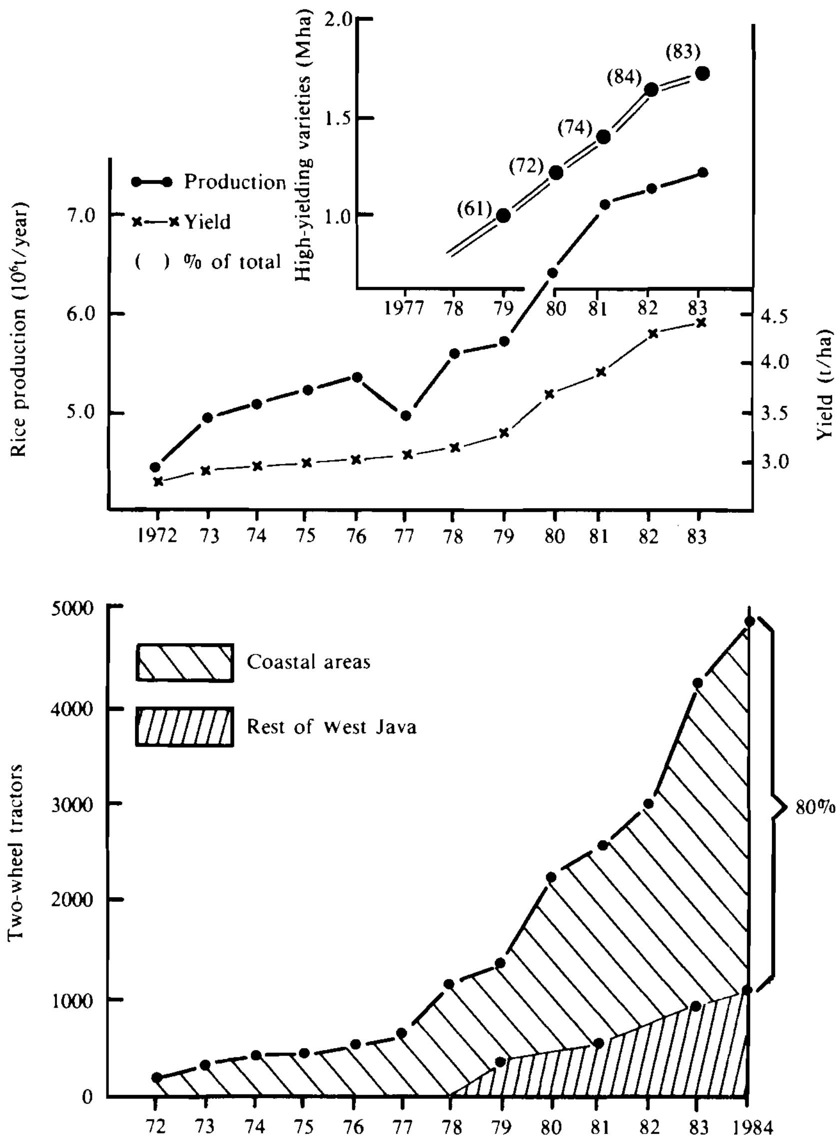


Fig. 2. Adoption of 2-wheel tractors and high-yielding varieties of rice in west Java as functions of increased production.

Bangladesh, Nepal, Vietnam, Burma, and Thailand all produce less than 2 t/ha and have less than 35% of their fields under irrigation. Within Indonesia and India, where the percentage of irrigated fields is less than 40, Java and Punjab, with almost twice as many

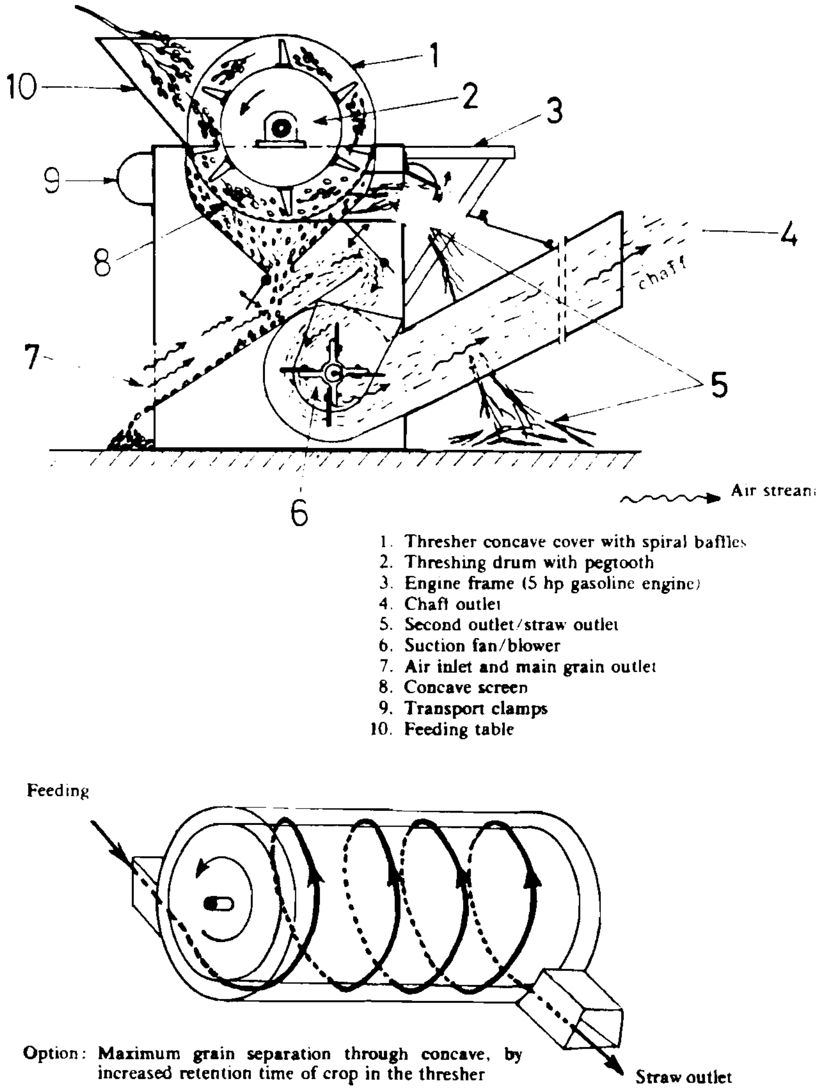


Fig. 3. Portable thresher designed by IRRI and adapted by Indonesians.

irrigated fields, produce twice the yields found in other rice-growing areas of the countries (Fig. 1).

In Java, irrigation made possible two crops of rice and was introduced along with high-yielding varieties. These changes produced marked shortages of labour even in this densely populated province; the result was that the farmers turned toward mechanized land preparation (Fig. 2), with about 65% of the power tillers being bought without assistance from government credit schemes.

The link between labour shortage and mechanization is absolute whether brought about by opportunities outside or within the agricultural sector. The more opportunities, the more rapid and sophisticated the mechanization. Thus, in technically advanced countries where intensive cropping is possible because of irrigation and where the industrial and technical sectors are productive, the pace of mechanization is high. In countries like Indonesia, the Philippines, Thailand, and India where technical improvements in agriculture (primarily irrigation, high-yielding varieties, and fertilizer inputs) are just being widely adopted and the proportion of people engaged in agriculture is large — 35–85% of the population — the drive toward mechanization is slower than in countries like Japan and the machinery developed is less sophisticated. Nevertheless, elements of equipment design and experience from the more advanced countries have been profitably adapted (Fig. 3–6).

A key factor is that the equipment must be suited to the size and characteristics of the farming system. For rice cultivation in tropical Africa at present, this primarily means equipment suitable for operations without effective water control. The rice-farming systems range from rather intensive smallholder farms to large-scale government-controlled estates applying extensive farming systems with only a part-time involvement of small farmers. With the exception of some irrigated projects, where mechanization systems are based on Western types of motorized equipment or on animal-drawn implements, most rice farming is carried out manually.

There are an overwhelming number of physical and environmental factors that constitute bottlenecks for the required increased labour and land productivity, both at the smallholder level and at the level of large estates: soil and water problems; lack of seeds, fertilizers; unique pests and diseases; energy and labour shortages; lagging postharvest technologies; inadequate marketing channels; etc.

Such limitations and uncertainties are disincentives to farmers, as are the low yields and high risks of crop failure.

The agricultural machinery industry in most tropical African countries is still in its infancy, focused in particular on the fabrication of hand tools, animal-drawn implements, and simple processing equipment. Fossil energy, steel, and other components of an industry for machine manufacturing are scarce and supply is irregular.

The buyers' market for farm machinery is variable because of instability of yields, uncertain prices for crops, and limited government credit programs. Technical skill and experience with engineering theory and practice are lacking, and facilities for repair and maintenance are almost nonexistent, particularly in the rural areas.

Although the degree of such constraints varies from one location to another, even within a country, the conditions for wetland rice growing in tropical Africa are much more difficult than those prevailing in most Asian countries. A rapid increase in productivity such as was realized in Asia thanks to the introduction of improved varieties, fertilizers, and appropriate agricultural equipment is not likely in most rice-growing African countries.

On the other hand, the gap between rice production and rice consumption is widening in most countries in Africa, and the potential for increased production is enormous both through the extension of rice growing in the wetlands and through the rehabilitation and intensification of the areas already being cropped

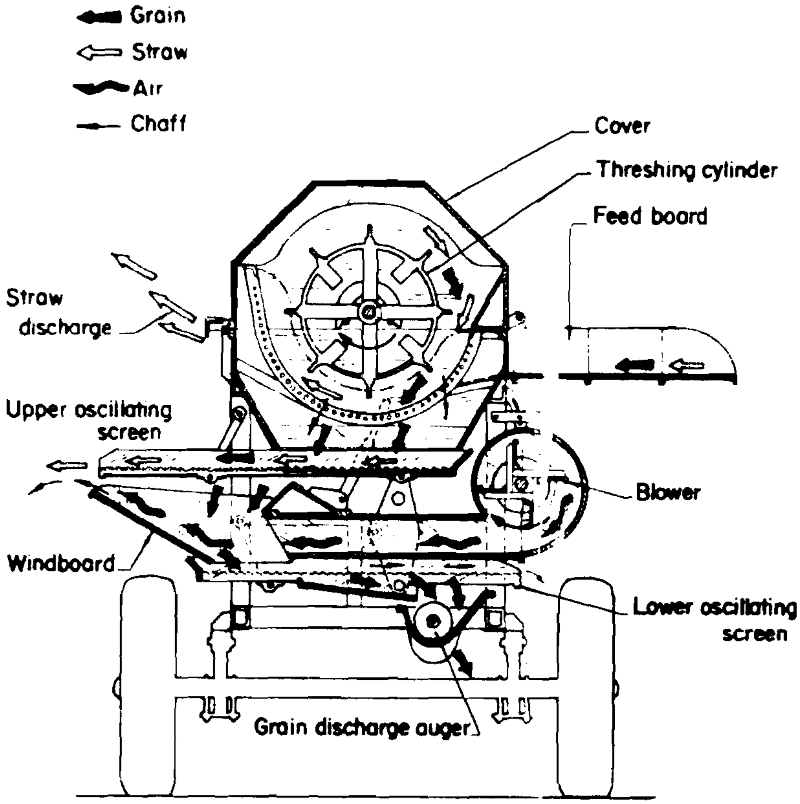


Fig. 4. Schematic of a larger axial-flow thresher that is commonly used in Southeast Asia, having been adapted in several countries, including Vietnam and Thailand.

to rice. Because seasonal shortages of labour are common in Africa even without intensive cropping, mechanization, if introduced in concert with other measures, can play a role now, at least in selected cases.

LARGE-SCALE PROJECTS IN RIVER BASINS AND DELTAS

For example, in concert with a system of water control, mechanized land preparation makes sense in large-scale projects in river basins, deltas, and mangrove swamps. Better water control, based on relatively small, level plots, served by a tertiary irrigation system, is a prerequisite for higher productivity. It minimizes the risks in rice cultivation and maximizes the benefits from better varieties and fertilizers as well as opening the way for more effective crop protection (especially weed control) and for rice mechanization systems that are technically, socially, and economically more acceptable.

At present, because the fields are not level and the water level is not controlled in a system of irrigation, no simple method exists to control weeds so they compete with the rice and reduce yields. Tillage operations can only be carried out in the dry season or before flooding when the soil is hard. Thus, the work is done only by medium or large tractors except in Mali where animal traction is common. This means that government or semigovernment agencies are the only groups who can undertake development of large river basins, deltas, and mangrove swamps.

Dry seeding of rice is the common practice, and yields are usually low. Harvesting is done manually, and the rice is threshed by large stationary machines, operating at relatively high costs (at capacities limited by the manual feeding method) and often with delays after harvesting and consequent postharvest losses.

Depending on local conditions, such as the availability of animal power, appropriate rice mechanization could be based on:

- Motorized equipment (standard types of Western tractors with their related implements and medium-sized rice threshers), such as applied in the new and rehabilitated ricelands of the Senegal river delta (in the project of the Société d'amenagement et d'exploitation du delta); or
- Sets of improved animal-drawn implements, such as developed and introduced in the improved rice polders of the "Office du Niger" in Mali.

MALI: ANIMAL-TRACTION TECHNOLOGIES

Mali has always had an agricultural sector dominated by animal

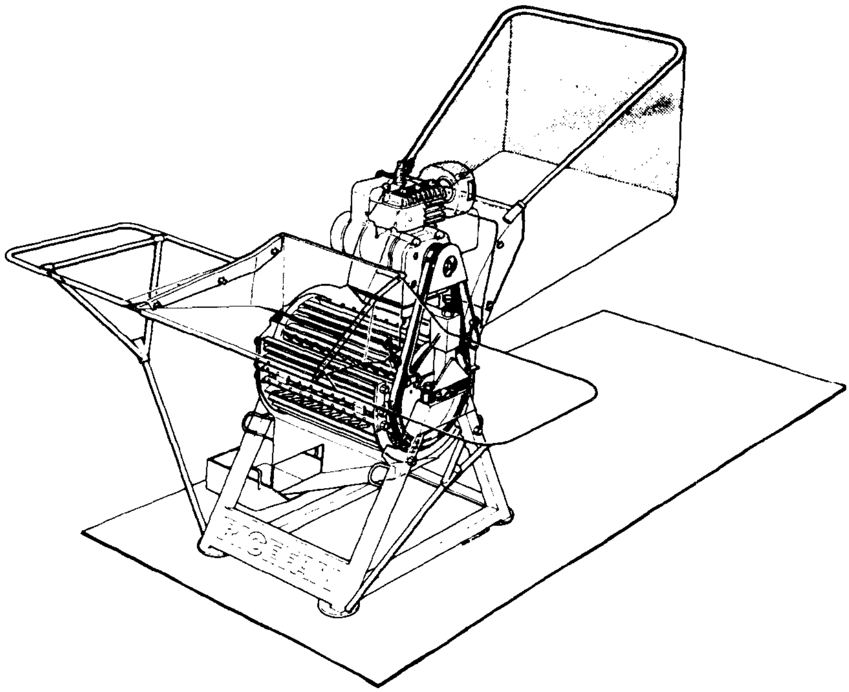


Fig. 5. Portable rice thresher designed in the Netherlands and manufactured with success in Asia, Africa and South America.

traction. In 1981 about 46% of all farms were equipped with animal-drawn implements; until recently, the mechanization was largely animal-drawn plows. Increasingly, however, other implements, in particular multipurpose tool carriers, levelers, and seeders are being introduced. Thus, animal power is being put to more effective use: increased numbers of operations during the cropping season. The animals are providing the power for secondary seedbed preparations, leveling and seeding as well as plowing. The changes make possible a system of rice cultivation that is more intensive and better controlled.

In the irrigated "Office du Niger" project area, the size of the fields is determined by the capacity of the animal traction technology, namely about 0.5 ha. Each farmer cultivates 3-5 ha of rice using one pair of draft animals for the tillage of 6-10 plots that can be independently irrigated. Row seeders, which are shared by several farmers, facilitate the weeding operations in the initial stages of rice growth. Small, portable rice threshers (capacity 150 t/season) are being used and are replacing the costly and inefficient large, stationary threshers. These portable threshers can enter the fields earlier than the larger models; they reduce the transport and handling and, ultimately, the losses of the harvested crop. Also, they are less expensive to operate than the large machines, with the result being increased participation by the farmers.

The developments have been supported by various training, extension, and credit programs. For example, rural blacksmiths have been trained in the maintenance and repair of the equipment. Animal-drawn implements and rice threshers are now being manufactured locally.

SMALL-SCALE PRODUCTION IN INLAND VALLEYS

Like large-scale production areas, small-scale rice-growing regions in tropical Africa have little or no water control, with the result being average yields of less than 1 t/ha. The possibilities for introducing improved rice mechanization appear limited at present, especially in the humid regions, where the use of animal power may be impossible because of diseases. Motorized equipment for tillage is probably not technically or economically feasible (difficult accessibility of the poorly leveled fields, low-bearing capacity of the soils, etc.).

Nevertheless, some projects have been launched to improve wetland cultivation in the inland valleys. Again, the key appears to be improved water control: construction of small dams, pumping

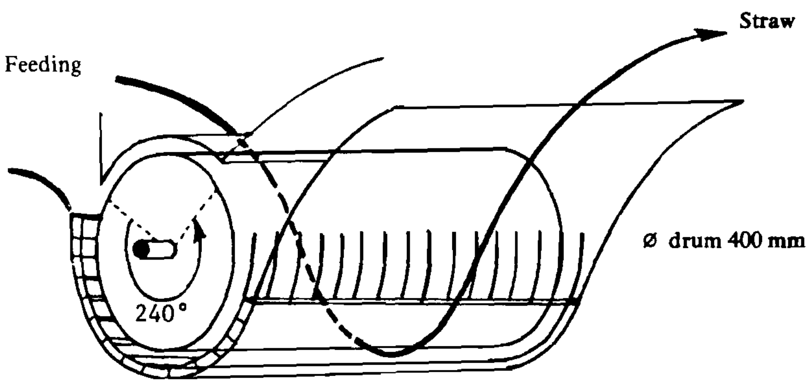
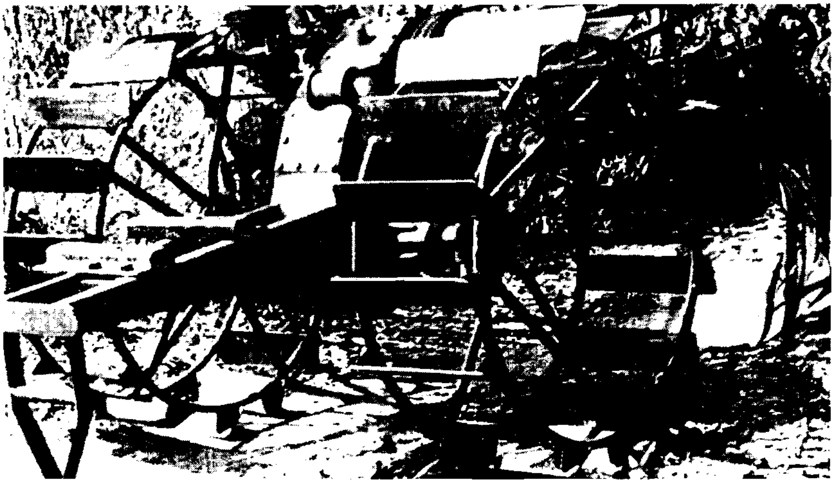


Fig. 6. Tangential-flow of the feeding mechanism for the thresher from the Netherlands. Direct flow of the crop through the thresher is possible — an option that eliminates clogging and makes the machine suitable for a wide range of crop conditions. Even with direct feeding, the relatively long concave ensures that 85-90% of the grain is separated.



Hand tractors have been developed in Thailand to relieve the labour requirements for plowing and harrowing.

stations, and (contour) leveling of the land. For example, Vallée du Kou in Burkina Faso and Amenagement de Guède in north Senegal duplicate Asian rice-growing conditions as far as field layout, leveling, and water control are concerned. Under these conditions, intensive cropping is possible, with the use of small power tillers and threshers.

Whether this experience could be generalized to the many other small inland valleys is doubtful at present. In particular, the small equipment built by the Japanese and Chinese may prove inappropriate technically and economically. For example, in Japan the rice prices and rural wages are 5-10 times those in most developing countries. Moreover, the purchase of advanced small machines for rice production is heavily subsidized, and more than 80% of farmers derive their main source of income outside agriculture. As a consequence, farmers in Japan can afford to use their power tillers and other agricultural equipment for only 100 h/year and to trade their machines in after only 500-700 h of use.

At present price levels in most developing countries, however, the same machines have to be used at least 600-800 h/year with a depreciation over at least 3000 h to be economically justifiable. Such an intensive use, nearly year round, could be realized in only exceptional cases and under ideal conditions.

The conditions in the wetlands of tropical Africa are far from ideal. The lack of water control, the uneven and inaccessible fields hinder the use of two- and four-wheel tractors and probably make the use of power transplanters completely infeasible. Lodging

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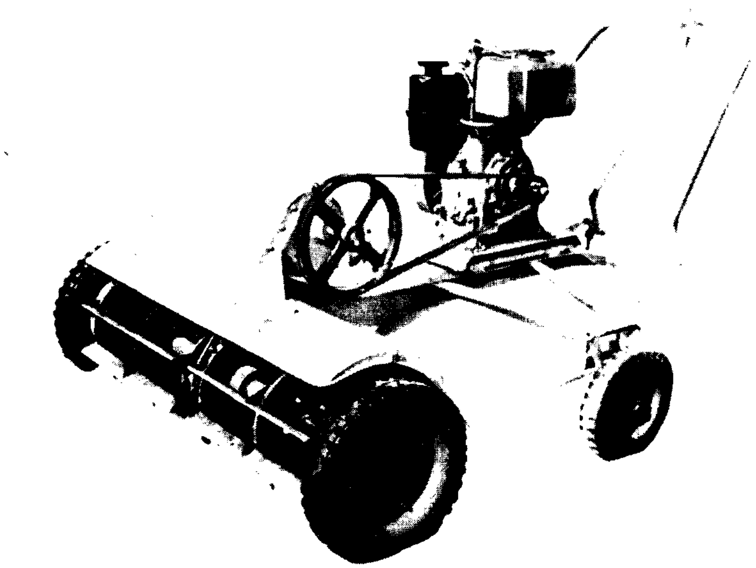
commonly affects the crop, ripening is uneven, and the fields have a low bearing capacity. Besides, the machines would be associated with heavy losses of the relatively easy shattering high-yielding varieties of rice, and the technical skills for operating and repairing the machines are currently unavailable.

These are the reasons that, of the whole range of small but sophisticated machines developed in Japan and Taiwan for rice cultivation, only the power tillers have found application on a reasonable scale in developing countries. Even the power tillers need simplification and reinforcement when adopted by developing countries.

More appropriate may be the types of equipment and tools built in Asian countries that are less developed than Japan. In Thailand, the Philippines, and Indonesia, small machines are locally manufactured for rice cultivation and processing. Some seem applicable to some selected regions in tropical Africa:

- For wetland tillage: simple hand tractors (of designs developed in Thailand or at the International Rice Research Institute in the Philippines) equipped with a plow and a simple puddling device; and the Philippine-made "floating power tillers" for soft, clayey soils;
- For rice harvesting: in particular the Chinese/IRRI designed swather-reaper, attached to a two- or four-wheel tractor; and



The floating power tiller designed in the Philippines may be adaptable to African conditions for wetland development.

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- For rice threshing: various types of axial-flow threshers as well as the portable rice-fan thresher.

These pieces of equipment, which were introduced with success in smallholdings in Asia, have advantages over the more advanced Japanese or Taiwanese models:

- Their lower prices;
- Their durability and thus suitability for less than ideal field and crop conditions; and
- Their simplicity of design and construction, incorporating local materials and minimizing the technical skills and facilities needed for maintenance.

They should be subjected to practice-oriented, on-the-spot research and testing in the prospective small-scale wetland-rice regions of tropical Africa. If they proved appropriate (with adaptations), they could be considered for introduction in a program of effective extension and agricultural credit, including adequate training and small workshop facilities for the required maintenance and repair in the rural areas.

Such a program would require cooperation between research and development agencies and machine manufacturers and tool makers:

- Within a given country for applied research and testing;
- Within a region for exchange of designs; and
- Within the international sphere for transfer of design and manufacturing know-how.

Principles of equipment design: examples from China

GUO FENG HUA and SHEN RUN ZHAI

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Abstract *Chinese engineers have designed and adapted machines to suit the mechanical properties of soils in the wetlands. The focus of work has been to produce implements that reflect the weight-bearing capacity of the soft, wet clays common in the country, that provide the traction needed for self-propulsion, and that minimize adhesion and rolling resistance. Sleds and paddle-type systems for propulsion are two of the basic designs commonly incorporated in the machinery.*

Efforts to mechanize rice production in the wetlands are hindered by the fluidity of the soil, including its:

- Low bearing capacity in the upper layer, resulting in increased rolling or moving resistance;
- Reduced shearing strength, causing self-propelled machinery to slide and rotate (reduced effective traction); and
- Increased suction and adhesion.

In other words, to develop suitable equipment, one needs to consider the physical and mechanical properties of the soil (for example, the coefficient of cohesion, angle of internal friction, specific gravity, moisture content), the physical parameters of farm implements (weight and its distribution, specific pressure, centre of gravity, and the geometrical configuration of the system of propulsion), and sometimes the dynamic parameters of the implements (velocity and acceleration).

Based on such data, we in China have been attempting to design and adapt appropriate tools and machines, and the amount of agricultural machinery has steadily increased (Table 1) as has the area of wetland under irrigation. At present, 45% of the cultivated area is irrigated and more than half by mechanical means.

Most of the irrigated land in the central and southern parts of

Table 1. Agricultural machinery in China, 1952-82.

Year	Total mechanical power ('0000s hp)	Tractors ('00000s)		Drainage and irrigation ('0000s hp)	Combines
		>20 hp	<20 hp		
1952	25	1.3	—	—	284
1957	165	14.7	—	—	1798
1965	1494	72.6	0.4	55.8	6704
1978	15975	577.4	137.3	502.6	18987
1980	20049	744.9	187.4	563.0	27045
1982	22589	812.4	228.7	589.3	33904

Fig. 1. Horse-shaped skid used in ancient China for the pulling and transplanting of seedlings.

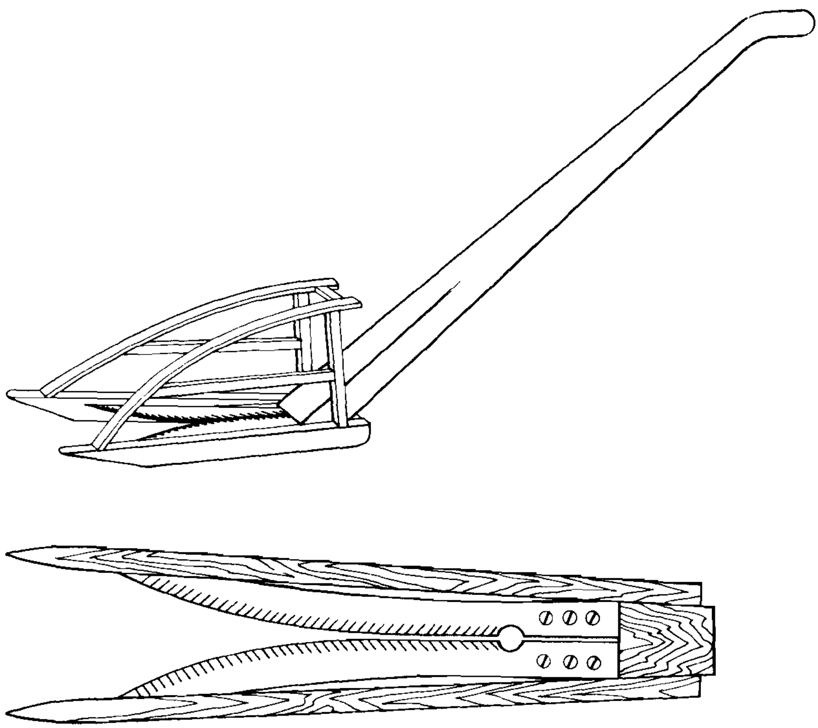

Fig. 2. Crop cutter mounted on sled.

China is clay loam, silty clay, and heavy clay, a soft layer about 10–30 cm deep in most areas. In some areas, the soft layer is 40–60 cm deep and is at times bottomless — called "flooded paddy field" in China.

WEIGHT-BEARING CAPACITY OF THE SOIL

Even in ancient China, efforts were made to alleviate labour intensity and to raise efficiency in rice cultivation. The horse-shaped skid (Fig. 1), for example, was designed for seedling transplanting or pulling.

Other tools that operate on the principle of reducing the downward pressure on the soil include manual rice cutters, which consist of two opposite sickles attached to a plate that slides along the surface (Fig. 2). The gap between the two knives is 1 mm and a crescent-shaped cut on each blade (forming a hole with a diameter of 1.5 mm) near the fulcrum prevents stems from becoming lodged in the tool. Such cutters are easy to guide and are stable, offering only

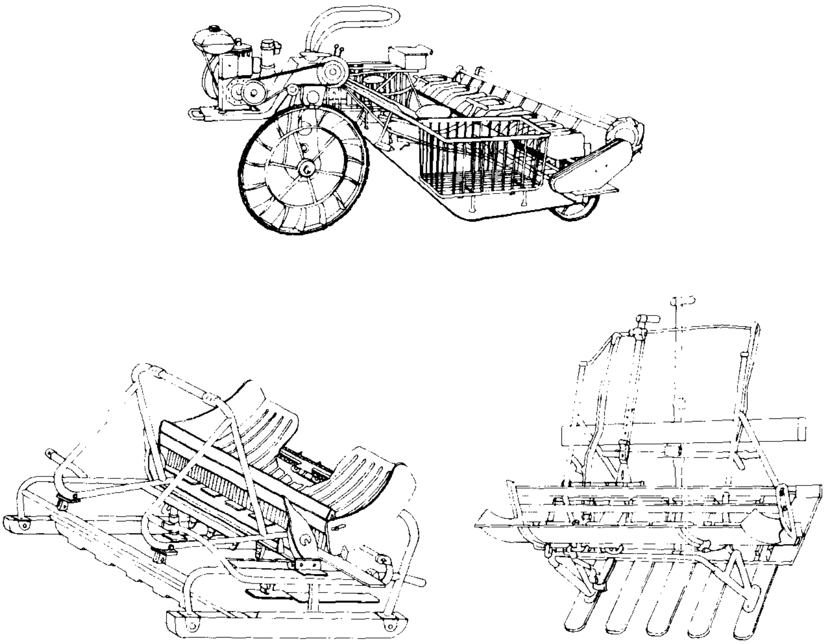

Fig. 3. Mechanical rice transplanter.

low resistance to forward motion. A pushing force of about 4 kg is needed to cut cereal crops with a single-row implement, and capacity is about 0.35–0.4 ha/workday.

Manual and powered seedling transplanters work on the same principle, incorporating sleds that distribute the pressure from the machinery (Fig. 3). The present design of the sled has evolved from what was essentially a three-sided box with rounded edges to a single-sided (rounded edge) plate mounted on long, narrow pieces of plate. The rationale was to reduce the contact (and thus friction) with the soil while maintaining good weight distribution. The capacity of a six-row rice transplanter is 0.24–0.36 ha/workday.

A 12-hp boat-type tractor is used in areas where the soft soil layer is virtually bottomless. A 740-kg prototype exerts minimal pressure (0.064–0.073 kg/cm^2) on the ground so will not destroy the soil structure. The design incorporates paddle wheels — one on each side — to produce traction; the maximal drawbar pull is about 300 kg for a 12-hp diesel engine. The rolling resistance (P_f) for a boat-type tractor decreases with depth of the fluid layer while the opposite is true for tractors on wheels (Fig. 4).

The coefficient of rolling resistance is greatly affected by the moisture content in the upper layer of soil. For example, a boat-type tractor having a bottom area of 130 × 80 cm^2 and weight of 320 kg has

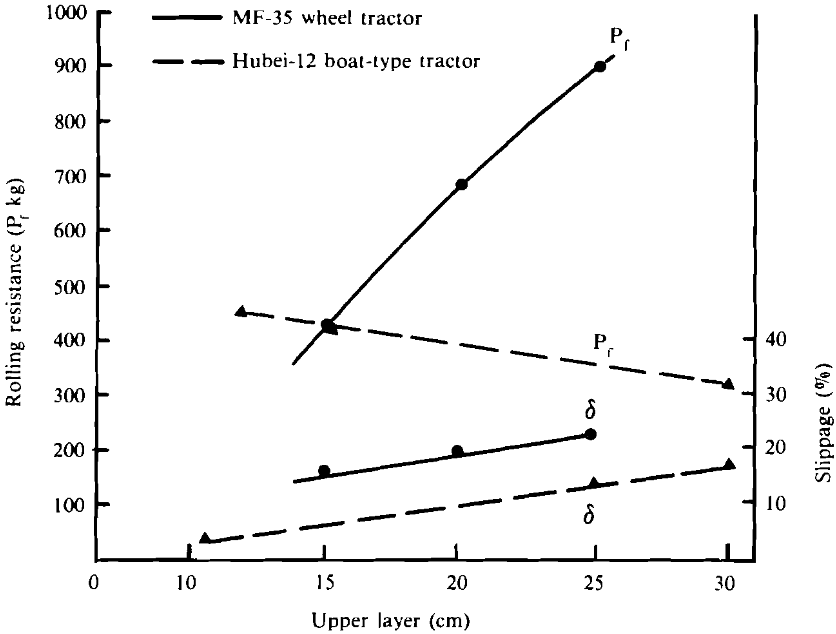

Fig. 4. Rolling resistance calculated for two types of tractor.

a coefficient of 0.1–0.2 at 40% moisture content and 0.66 at 15%. A slight angling of the bow (about 2°) during forward movement decreases resistance.

INCREASING TRACTION

The mobility and traction efficiency of self-propelled implements or tractors are closely related to the shearing strength of the soil, which largely determines the drawbar force — the difference between horizontal thrust and rolling or moving resistance.

Calculating soil thrust is difficult, but the thrust force (H) under a given load (W) can be expressed by Columb's law:

$$H = AC + W \tan \phi$$

where A is contact area and C is coefficient of cohesion (0 in nonadhesive soils). On sandy soils, one can improve the thrust force by increasing weight. However, most of the soils in paddy fields in China are clay loam or silty clay, their values for C and for ϕ are both low. Increasing weight, therefore, will not only increase subsidence but also raise the rolling resistance.

Cage-like structures (Fig. 5) can be attached to tractor wheels to counteract slippage. They are structurally simple and easy to install

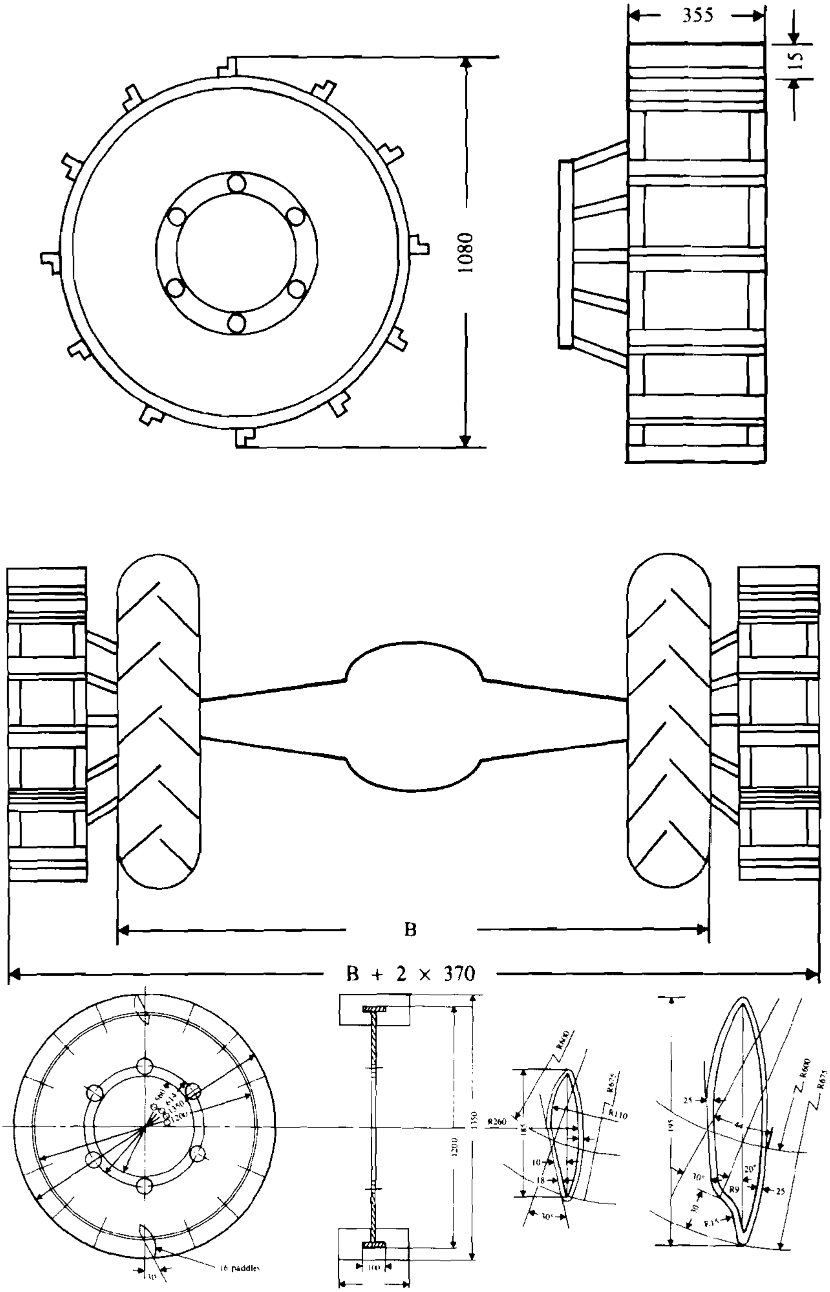

Fig. 5. Cage-like structure to improve efficacy of tractor wheels in wetlands.

but tend to exacerbate compaction of the soil. In wet clays, raising soil thrust, hence the drawbar pull, by increasing the vertical load is counterproductive because of low capacity for weight bearing. However, one can increase the contact area by increasing height of the grouser (or tire tread) (Fig. 6). If the grouser makes contact with the hard layer beneath the fluid clay, the thrust is geometrically increased.

In the 1950s, paddle-type steel wheels were extensively used in China to take advantage of this principle in the wetlands, and a simplified paddle wheel, with changeable plastic or rubber tread, is still used on the small "walking tractors" (Fig. 6) and on boat-type tractors (Fig. 7). These wheels work well in irrigated soils with a bearing capacity of 2-9 kg/cm^2, but their rolling resistance is larger (coefficient > 0.3) than that of rubber tires.

A deep-lug rubber tire with a pressure 0.8 kg/cm^2 is now widely used in tractors for the wetlands. It has a low coefficient of rolling resistance (0.26-0.28) and, at light loads, better traction than steel wheels.

MINIMIZING ADHESION

When soil adheres to an implement, eventually it impedes or halts progress. To solve this problem in China, farmers usually increase the moisture content of the soil.

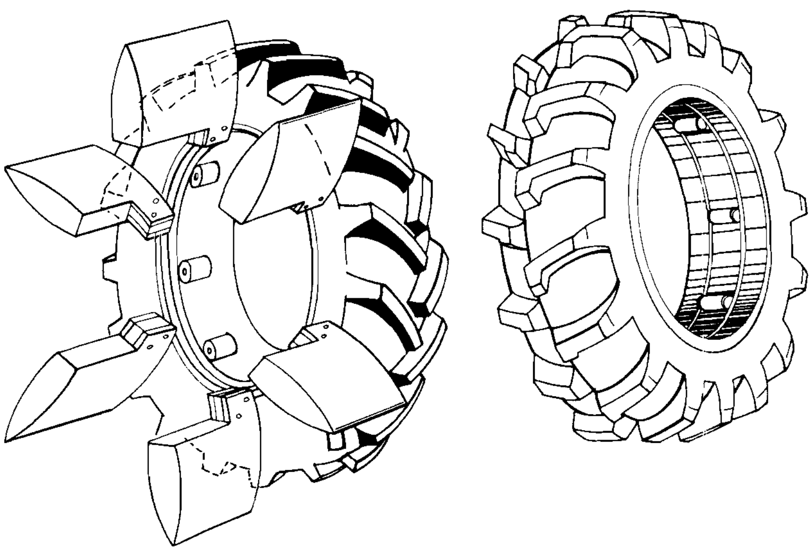

Fig. 6. Steel paddle that attaches to tires of walking tractors, left, and deep-lug rubber tire suitable for wetland use.

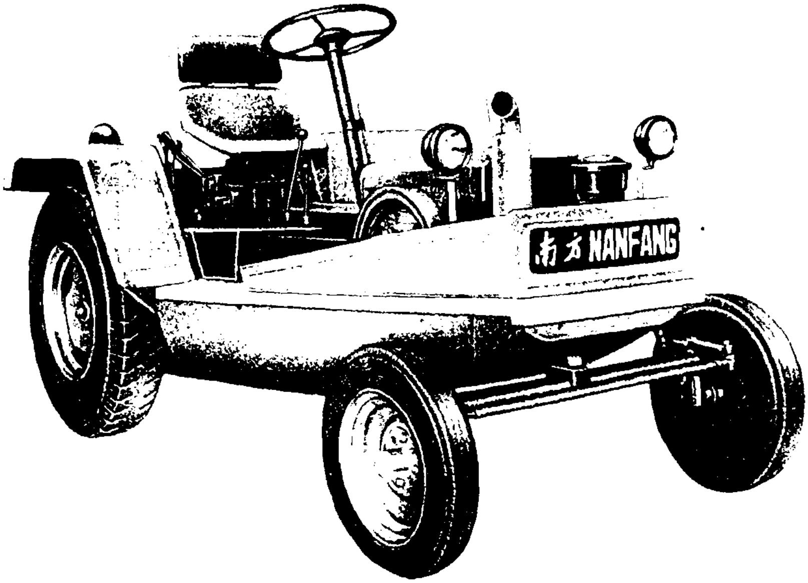

Fig. 7. Idealized version of boat-type tractor.

CONCLUSIONS

Chinese researchers studying the complex problems of mechanization in the wetlands have promoted the use of:

- Boat or sled-type chassis, especially in soils with a deep soft upper layer;
- Paddle-type systems that propel machines, especially in deep or "bottomless" soft soils;
- Antiskid cages or paddle-type wheels attached to tires for operations in not so deep soft soils after plowing;
- A slight upward angle at the front of the machine, the degree depending on the weight of the machine and the centre of gravity; and
- The soil mechanical principle as a basis for the design of equipment.

Tools and implements for rice farming

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Abstract *Some tools developed for rice cultivation in the wetlands in Asia promise to be useful in Africa as well. They are being tested and adapted to the arduous conditions in Africa and the limited infrastructure for local manufacturing and repair. The animal-drawn plow would be ideal for land preparations in areas of Africa where livestock can be raised.*

Among all the tools and implements for smallholders engaged in rice farming, animal-powered techniques for rice cultivation, as used in Asia, seem particularly appropriate for Africa in areas where livestock production is feasible. If animal power could substitute for human power in arduous tasks such as land preparation, a significant step forward will have been taken.

LAND PREPARATION

The animal-drawn plow is a basic tool for land preparation in the Philippines, Thailand, and Burma. The fields are soaked for a few hours so the soil is soft, and a water buffalo is used to pull the plow. A single animal can work continuously for 2 hours during the cool periods of the day. The standing water (and an occasional dousing) cools the animal enough to enable it to withstand the heat.

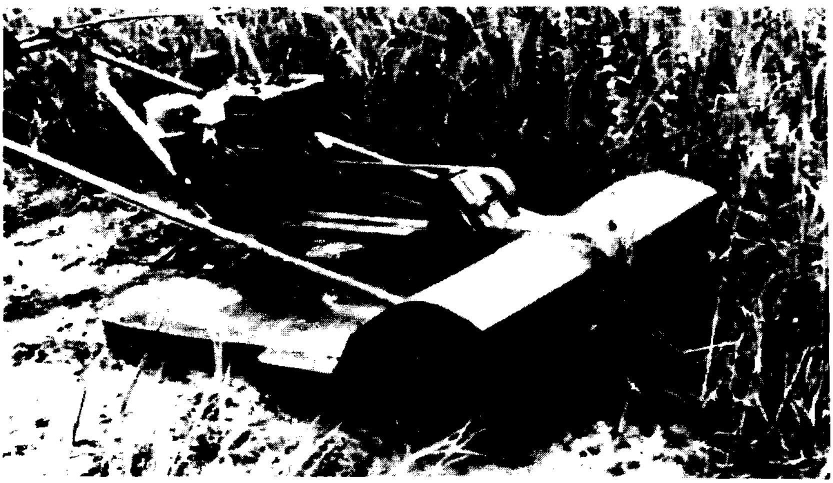
The plow used in the Philippines has a wooden frame, although a steel frame would be needed in Africa because of the requirement for sturdier equipment with less maintenance. The design is simple, and people can be quickly trained to fabricate the plow and its accessories (yoke and single tree). It is normally used along with the comb-tooth harrow, which is another basic implement for land preparation.

These two implements plus a water buffalo weighing 400 kg expand almost immeasurably the farmer's capacity to till the land. However, the equipment cannot be operated effectively unless:

- The farmer is trained in animal care and in the operation of the plow and harrow to achieve a level, puddled soil;
- The animal is trained (while young) to pull the plow and harrow;
- Water is available on time and in sufficient quantities;
- Drainage is good;
- Soil is clay or clay loam;
- Fields are long and narrow as well as being laid out along the contour to avoid extensive earth moving.

Power tillers or hand tractors are much faster than animals but are also more expensive. They are not readily available unless being produced locally. Such implements are now being manufactured (except engines) in the Philippines, Thailand, and Indonesia. They are an IRRI design, which was meant to be simple and cheap to construct.

One Philippine design, called the "turtle" or floating power tiller, is suited for very soft and deep soils. It floats along the surface — a feature that makes it adapted for soils with deep hardpans. Fields prepared by this tiller do not require plowing, whereas other simple power tillers are effective only in fields that have been plowed and



At IITA, the floating power tiller has been given side plates to minimize clogging by weeds wrapping around the rotors and has been fitted with a longer handle.

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given several passes with the comb-tooth harrow. This tiller has been adapted and modified at IITA. The operating handle was made longer for convenient control by African farmers, and the float body was made wider to increase the area of contact with the ground. This latter change ensured that the machine was propelled forward in a straight line and enhanced the capability of the machine for land leveling. The side fenders were removed because they hindered operation when they hit stumps or large stones in the field. The rotor blades were made of thicker steel bars to minimize wear, round plates were added to each end of the tilling rotor to minimize buildup of weeds in the assembly, and an idler pulley was incorporated to maximize contact between the belt and the engine-drive pulley.

In Asia, leveling is done with the harrow, a wooden plank being placed over the row of teeth. The operator gauges the work by the standing water on the land. An animal-drawn harrow has some advantages over a motor-driven machine in that it eliminates the ruts associated with the wheels and reaches the edges of the field. In fact, farmers in Asia who have access to both sources of power employ animal power for the finishing touches.

The normal labour requirements for plowing, harrowing and power rotary tilling of a wetland rice field are:

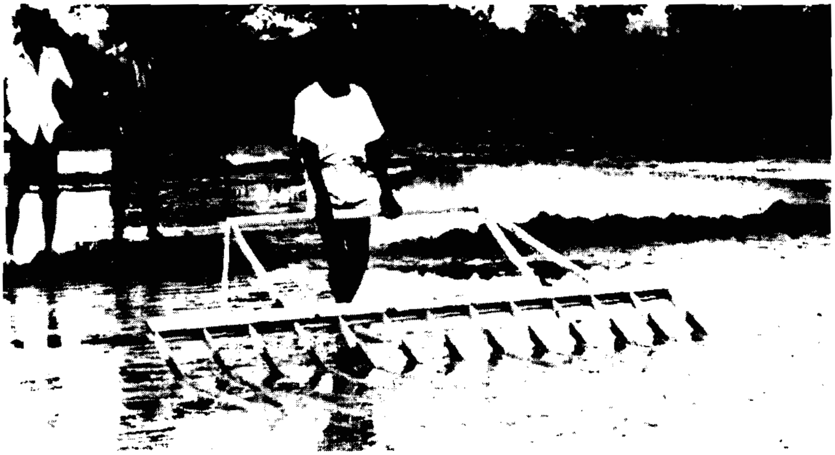
- Plowing — single animal plus moldboard plow, one pass, 30–60 h/ha; 3-hp power tiller, 15 h/ha.
- Harrowing — single animal plus comb-tooth harrow, 3-6 passes, 40–60 h/ha; 3-hp power tiller with comb-tooth harrow, 9 h/ha;
- Rotary tilling — 8.5-hp, power tiller, 9 h/ha; 8-hp adapted tiller for puddling in Africa, 10–12 h/ha.

CROP ESTABLISHMENT

In the early 1970s, manually pulled multirow seeders were developed by IRRI and introduced in the Philippines. They were not readily accepted by farmers partly because direct seeding is less common than transplanting and partly because of design deficiencies. Their use is being revived through an improved design as direct seeding is seen as a means to decrease labour costs. In Africa, direct seeding is common because of labour shortages so the design is likely to be adaptable.

In Asia, however, transplanting is still the more common practice. While the cost is high, the advantages over direct seeding are early establishment, even stands, and good weed control. Direct seeding requires precise leveling of the field and water control.

IRRI developed a manually operated six-row transplanter as well as a technique to supply uniform seedlings for it. The nursery



In well-prepared fields, a marking guide can be used to ensure planting is in straight rows suitable for mechanized weeding.

technique entails no investment in equipment and requires only a few hand tools. In contrast, an elaborate nursery technique is needed to produce seedlings for the motor-driven transplanters available from Japan and Korea. The use of the IRRI transplanters is being popularized in Indonesia, the Philippines, Sri Lanka, and Thailand. Training of farmers in nursery growing, machine operation and maintenance is crucial to the success and acceptability of the transplanter.

A team of transplanters follow the line from a marking guide as they plant one or two seedlings per hole.

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A rice transplanter that can be attached to a power tiller has been developed and commercialized in South Korea, and a similar prototype, based on Chinese design, is being tested in the Philippines. The aim is to increase the versatility of the power tiller.

The capacities of different transplanting methods are:

- Manual, 160-200 h/ha;
- Six-row mechanical rice transplanter developed by IRRI, 20-26 h/ha;
- Power tiller with an attached 4-row rice transplanter developed by the Korean Agricultural Mecanization Institute, 6.6 h/ha;
- Prototype 5-row transplanter attached to power tiller, developed at the University of the Philippines, Los Baños, 5 h/ha; and
- Self-propelled Japanese rice transplanter, 2-row design, 16.7 h/ha and 4-row design, 8 h/ha.

CROP CARE

The technology for crop care — protection from pests, diseases, and weeds; irrigation; and application of fertilizers — is well-established among farmers in Asia.

Rotary weeders, mostly of the manual push type, are available but can only be used in straight, evenly spaced rows. The rotary blades are made of thick-gauged sheet metal and are attached to a roller and float pad. The apparatus is mounted on a wooden frame or on a frame of metal pipe.

This design was modified recently by the Agricultural Mechanization Development Program of the University of the Philippines: a double-row rotary weeder was developed that does not require much more pushing effort than the single-row weeders. Three-row weeders have been tested but are difficult to push except in very soft soils with relatively few weeds.

A rotary weeder was also modified by IITA staff for use in Africa because the IRRI design performed poorly in field trials by IITA, particularly on hard, sandy soils. To improve the performance, IITA staff made the blades narrower and stronger as well as increasing the size of the float so that it would hold additional dead weight.

For chemical weed control, the most common sprayer in Asia is the knapsack-type with wands for nozzles. Its disadvantages are:

- The operator walks into the spray of chemicals;
- Chemicals often drip onto the neck and back of the operator;
- The hands of the operator are likely to be contaminated during preparation of solutions from concentrated ingredients; and

IITA made the Asian rotary weeder stronger and narrower for use in Africa.

- Spray droplets are not evenly distributed.

Still the knapsack sprayer is currently the most suitable technology for smallholders. At IITA, the knapsack sprayer was adapted for wider coverage: a 5-m boom was attached and several nozzles were added. Spraying is a two-person operation, with the boom being held horizontally by one person along the path of travel.

Irrigation pumps to lift water 1-4 m are available commercially; however, their efficiency is low. An IRRI pump — the "sipa" — is an axial-flow type operating efficiently at low lifts. For small paddy fields, a double-cylinder pump with pedals for foot operation can be used. It is cheap and easy to make from indigenous materials. Its capacity is low but is still higher than that of many traditional scooping methods, and its operation is much less arduous.

Fertilizers are commonly broadcast by hand rather than being applied mechanically but wastage is high.

IITA produced a manually operated fertilizer applicator that incorporates a metering device and applies the fertilizer in bands. Its components are a handle, an offset wheel, a wooden hopper, taped auger, sliding gate, and spout.

The energy requirements and capacities for crop care are:

- Hand weeding (pulling by hand and burying the weeds by feet) 350-400 h/ha;
- Hand-pushed rotary weeder: single-row type, 30-85 h/ha;

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double-row type, 25–45 h/ha; and three-row type, 55 h/ha;

- Engine-powered triple-row weeder, 11 h/ha;
- Manual knapsack spraying, 10 h/ha;
- Boom spraying (16-L knapsack), manually operated six nozzles, 3-m swath, 3.7–5.5 h/ha; five nozzles, 5-m swath, 2–4 h/ha;
- Engine-powered dust and mist blower: spraying, 3.5 L/min at 7 m; dusting, 5.32 m^3/min at 10 m; and
- Fertilizer application: hand broadcast, 4 h/ha; 2-row fertilizer applicator, 16 h/ha.

HARVESTING AND THRESHING

The manual method of rice harvesting is still prevalent in Asia and Africa. The sickle is commonly used to cut the stems near the base. In Indonesia, the "ani-ani" is still being used to cut the panicles, especially for the native tall varieties that do not shatter as easily as the high-yielding ones.

Recently, a vertical conveyor–reaper, designed in China to windrow the cut crops, has been adapted for farmers elsewhere in Asia. In the Philippines, it has been modified as an attachment to the front end of a power tiller, whereas in Pakistan it is attached to four-wheel tractors.

Modern combines that harvest, thresh, and sack rice in one pass through the field are suitable only for large, level fields of uniform crops where weeds are few and the field can be drained during harvest. Moreover, they require large capital investments.

Several manual methods of threshing are common. The panicles are beaten against bamboo slats or on hard wood over a wide mat to catch the flying grains; they are beaten by flail, rubbed with the feet; or fed onto a drum thresher.

A threshing ring (hampasan) has been introduced to African farmers by IITA. The cut rice is beaten on circular metal rings arranged in five tiers, the entire contraption being surrounded by canvas to minimize losses of the grain. The setup is portable and is placed over a mat at the site of threshing. It has been found to be effective for threshing both rice and upright cowpea.

In Asia, rice is also sometimes threshed by means of a team of animals that trample a mat of the harvested crop. Mechanically powered threshing is by concave threshers with either a cross-flow or an axial-flow drum.

The axial-flow thresher is now common in the Philippines, Sri Lanka, and Thailand and is becoming popular in Indonesia. IRRI has a small, portable model run by an 8–10-hp engine and a medium-sized model run by a 16-hp engine.

Traditional rice threshing in southeastern Nigeria.

The energy requirements and capacities of harvesting and threshing operations are:

- Manual harvesting using sickle, 120-160 h/ha;
- Mechanical harvesting by power tiller with an attached reaper, 1.0 m, 5 h/ha; and 1.2 m, 4 h/ha;
- Human and animal-powered threshing — beating on slats or hard wood, 150-160 h/ha; pedal threshing, 50-100 kg/h; hampasan (threshing ring), 14-18 h/ha for rice and 250-300 h/ha for cowpea (including harvesting, beating, and cleaning);
- Mechanically powered threshing — 5-hp portable drum thresher, 300-600 kg/h; 7-hp axial-flow thresher, 500 kg/h; and 10-hp axial-flow thresher, 1000 kg/h.

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DRYING

For safe storage, the moisture content of the rice should be about 14%. Drying is necessary and is crucial for crops that are high in moisture or are harvested during wet weather.

Sun-drying is the commonest and cheapest method if the weather is suitable for sun-drying. Low-cost mechanical dryers, mainly the batch type, are available and would certainly be within the means of cooperative groups of farmers. Heating sources are kerosine or diesel fuels or rice husk, depending on the design of the furnace or the heating unit. The blower for moving hot air through the bin of paddy is powered by either an engine or an electric motor.

The capacities and labour requirements for cleaning and drying of rice are:

- 5-hp grain cleaner, 1 h/t;
- Sun-drying 8 h/t;
- Mechanical drying: batch type, 277 × 190 × 92 cm steel bin (3 hp), 4–6 h/t; batch type, 344 × 173 × 158 cm wooden vertical bin (5 hp), 2 t/load (2% moisture reduction/h).

CONCLUSIONS

The experience has been that some Asian tools can be adapted for rice farming in Africa but only after thorough evaluation and modification. A number of such tools and equipment are now being tested and introduced to farmers in Africa through the cooperation of national agricultural agencies.

DISCUSSION SUMMARY

Many socioeconomic surveys conclude that acute shortages in farm labour are a major constraint to rice production, but at the same time they also indicate that mechanization on small farms is not economic. What is the view from agricultural engineers?

Mechanization cannot be judged in isolation; it is one component of a production system or package. If all other production factors are met, mechanization on small farms can be profitable.

How can the problems of postharvest processing, storage, and utilization be solved?

Given present rice farming in Africa, I think development of small-scale industries similar to those operated in China, Thailand, and Indonesia is a good solution.

What are the recommended tools and machinery for clearance of wetland for rice farming?

There is no specially designed machinery. Usually land clearing is done during the dry season. Manual clearing is cheaper than clearing with heavy machinery, which can be very costly.

Although modern machines for small farms in Japan and Taiwan may be too sophisticated for Africa under present conditions, why aren't less-sophisticated machines and farm implements from countries such as the Philippines, Thailand, Indonesia, and China being transferred here?

Local manufacturing and maintenance are probably major factors.

TRANSFER OF TECHNOLOGY

Nigeria's program for wetland rice production and rice research

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Abstract *The wetlands in Nigeria account for about 75% of the country's total production of rice. The amount of paddy produced has increased from 350 000 t in 1970 to 1.5 Mt in 1983. The increases reflect the growing demand and the improved techniques being applied as a result of research, extension, and development efforts for rice. Studies of soil fertility, varietal improvement, crop protection, cultural practices, and farming systems have been under way in the country since the 1950s. They are coordinated by the National Cereals Research Institute.*

Systematic research on wetland rice in Nigeria started in 1951 with the opening of a rice research station at Badeggi by the Federal Department of Agricultural Research, and this station has now become the headquarters of the National Cereals Research Institute. The impact of the work of this station is manifested in the contribution of wetland rice to total national rice production. Current estimates are that the wetlands currently under rice cultivation (300 000 ha) account for 75% of the national rice production (Ayotade and Okereke 1984).

PRODUCTION

The wetlands comprise inland swamps (10% of the total area of rice production), mangrove and freshwater swamps (5%), shallow to deepwater fadamas (20%), and irrigated plots (5%), with contributions to national rice production being, respectively, 20%, 1%, 45%, and 10%. The estimated production of paddy in Nigeria (Table 1) rose from 350 000 t in 1970 to close to 1.5 Mt in 1983.

The increase in production largely reflects improvements in

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Table 1. Estimates of rice production and consumption in Nigeria, 1970–83.

Year	Area ('000s ha)	Production ('000s t)	Yield (t/ha)	Estimated imports ('000s t)
1970	255	345	1.35	1.7
1971	304	385	1.26	0.3
1972	237	447	1.87	5.9
1973	373	487	1.30	1.1
1974	269	252	1.95	4.8
1975	261	515	1.97	6.7
1976	278	534	1.92	45.0
1977	348	667	1.92	413.0
1978	360	695	1.93	770.0
1979	430	850	1.97	700.0
1980	558	1105	1.98	680.0
1981	602	1240	2.05	653.0
1982	630	1330	2.11	na
1983	650	1550	2.38	564.0

[a]na = not available. The figures have been taken from records of the National Cereals Research Institute, the Nigerian Trade Summary, the Federal Department of Agriculture annual reports, and WARDA yearbooks.

production packages brought about by research and government efforts in extension and development.

Nigeria's research on wetland rice is carried out at Badeggi (for shallow swamp rainfed and irrigated rice), Bende (for inland swamp rainfed rice), Birnin Kebbi (for deep swamp and floating rainfed rice), and Warri (for tidal swamp rainfed rice).

There are 25 other testing stations in the rice-growing areas of the country. All these sites are part of the National Cereals Research Institute, which has the mandate for all rice research in the country.

The broad program of research includes studies on soil fertility, varietal improvement, cultural practices, physiologic characters, crop protection, and processing.

SOIL FERTILITY

In one group of studies of soil fertility, 410 topsoils from the wetlands were analyzed (NCRI 1977, 1978, 1979; Ayotade 1980; Ajayi and Ayotade 1985) (Table 2): the results indicated a wide range of pH (H_2O) values (4.3-8.8), with 51% of the samples being strongly acidic; contents of extractable K, Ca, and Mg were moderately high, whereas organic matter and P were extremely low (Table 3). Some experiments to test the effects of fertilizer applications were also

Table 2. Agroclimatic and soil conditions of sampling sites.

Agroclimatic zone	Dominant soil conditions	Samples
Sahel savanna	Weakly differentiated soils or with combic or argillic B horizon; often saline, sodic, calcic, gypsic properties (mainly Vertisols)	2
Sudan savanna	Soils with argillic or combic B horizon; high CEC, high base saturation, with expanding clays (mainly Alfisols and Vertisols)	23
Northern guinea savanna	Soils with argillic or oxic B horizon; low CEC, mid to high base saturation; isolated areas of soils with high CEC and expanding clays (mainly Ultisols and Alfisols)	350
Equatorial	Soils with oxic or deep argillic B horizon; low CEC, low base saturation (mainly Oxisols)	35

conducted. During 1976-79, the effects of NPK treatments were monitored on four benchmark sites (Tables 4 and 5). At the levels applied, N increased yields at all except one site (Bende), and, throughout the 4 years of cropping at three of the locations, the response to combined NPK application remained fairly constant.

The efficiency of N was doubled when the fertilizer was concentrated in the root zone of the rice plant. About 54 kg N applied to the root zone either mixed in mudballs (Ayotade 1971) or as sulfur-

Table 3. Fertility indices of topsoils in Nigeria (Panabokke and Nagarajah 1964).

	Fertility class					
	Low		Medium		High	
Indicator	Index	% of soils	Index	% of soils	Index	% of soils
pH (H_2O)	<5.2	51	5.2-7.2	47	>7.2	2
K (meq/100 g)	<0.2	31	0.2-0.25	11	>0.25	58
Ca (meq/100 g)	<2	32	2-4	32	>4	36
Mg (meq/100 g)	<1	39	1-2	34	>2	27
Organic matter (%)	<3	96	3-5	4	>5	0
Bray P-1 (ppm)	<7	70	7-20	29	>20	1

Table 4. Properties of soils at four experimental sites in Nigeria (Ayotade 1980).

	Site			
	Badeggi	Edozhighi	Bende	Ngala
Soil order	Ultisol	Ultisol	Inceptisol	Vertisol
Texture	Sandy clay	Silty clay	Clay	Clay
pH (H_2O)	5.8	5.3	5.1	7.4
K (meq/100 g)	0.10	0.09	0.58	1.34
CEC (meq/100 g)	4.7	7.2	39.6	41.3
Total N (%)	0.02	0.06	0.34	0.26
Organic matter (%)	0.46	0.90	4.40	3.40
Bray P-1 (ppm)	10	13	28	26

coated urea (SCU) or in large urea super granules consistently produced as much rice as 120 kg/ha applied as top dressings, a practice commonly followed by farmers. Other studies have established optimal rates, methods, and timing of applications as well as sources of N (Ayotade 1971), P, and K (NCRI 1977, 1978, 1979) fertilizers for wetland rice on some benchmark locations.

Zinc deficiency has been reported in a few areas (Kang and Okoro 1976) and may hinder rice production in the future, particularly in southern and northern guinea savannas where Oxisols, Ultisols, and Vertisols are found (Lombin 1980, 1983; Kang and Osiname 1985).

Table 5. Effects of NPK fertilizer on grain yield of lowland rice grown on four experimental sites in Nigeria (mean of three varieties and four replications, 1976-79) (Ayotade 1980).[a]

Treatment (kg/ha)[b]			Grain yield (t/ha)			
N	P	K	Badeggi	Edozhighi	Bende	Ngala
0	0	0	1.4a	1.5a	4.8ab	4.9a
120	0	0	2.0bcd	1.9ab	4.7ab	6.7c
0	60	0	1.6ab	1.7a	4.6a	5.4a
0	0	60	1.6ab	1.4a	4.9ab	5.9ab
120	60	0	2.6cde	2.4bc	5.2bc	6.2abc
120	0	60	2.2bc	2.2bc	5.2bc	6.6bc
120	60	60	2.7de	2.6c	5.5c	6.6bc

[a]Numbers followed by the same letter do not differ significantly at the 5% level of probability.
[b]The source of phosphorus was P_2O_5 (60 kg/ha) and the source for potassium was K_2O; the results for Ngala are for 1977 only.

VARIETAL IMPROVEMENT

Because the soils are nitrogen-poor in general, the early efforts in crop improvement by NCRI were devoted to finding varieties of rice that performed well on the limited nitrogen supplies available in the soils and under the cultural practices common in the country.

FARO 1 (BG 79) was the first popular white-grained variety in this category, and although late maturing and susceptible to diseases and pests it produced good quality grain and was grown widely by farmers for a long time.

In the later part of the 1960s, however, early maturity and high yield began to be emphasized for use in double cropping in the irrigation schemes being established in the country.

An "ideal plant type" for tropical varieties was described by IRRI, and some varieties that resisted lodging, responded well to nitrogen, and produced high yields were either introduced and adapted or bred in the country. Prominent among the introduced and adapted varieties were IR8 (recommended and released as FARO 13), FARO 15 (BG 79 × IR8), FARO 16 (Tjina × TN1), and FARO 17 (Mas 2401 × TN1). Some of these varieties possess grain qualities similar to the well accepted "local varieties".

FARO 27, an early maturing variety, was developed later to replace FARO 21 in the wetland rice areas because of its better quality of grain and higher potential yields. More recently, we have increased the range of early maturing, high-yielding, long-grained varieties such as FAROX 233-7-1-1 and FAROX 228-3-1-1 for specific

Table 6. Agronomic characters of the 10 best entries selected from 463 entries in the international rice cold tolerance nursery 1979–80 dry season (November–March), Badeggi, Nigeria (Ayotade and Akinyemi 1984a).

Entry	Yield (t/ha)	Maturation (days)	Plant height (cm)	Spikelet fertility	Panicle exsertion	Acceptable grain
RPKN-2	4.4	115	118	+	+	+
B2012C-KN-15-1-3-2-3	5.6	121	122	+	+	+
Kulu	4.8	121	119	+	+	+
KN-361-BKK-27-1	4.4	115	118	+	+	+
IR9202-36-3-2	6.0	139	100	+	+	+
B737F-KN-10-3-1-2	5.6	118	120	+	+	+
IR9202-25-1-3	7.2	120	108		+	+
IR8965-K1	6.0	122	77	+	+	+
IR9224-K1	6.0	106	94		+	+
IR9202-22-3-2	6.8	139	99	+	+	+

Table 7. Effect of silica content on damage caused by the African striped borer (*Chilo zacconius*) in different rice varieties (Ukwungwu 1984b).

Cultivar	Silica (% of stem)	Bored stems (%)	Surviving larvae	Larval weight (mg)
IR34	7.5	16.4	9.1	57.2
B9C-ma-3-3	7.6	36.8	9.9	59.6
ADNY 2	7.8	35.9	12.3	64.3
Irrigated saline/alkaline cultivar from Ghana	7.9	29.3	9.6	54.8
IR8	8.0	21.2	9.0	60.9
Improved Mahsuri	8.4	34.8	11.6	59.6
FARO 11	9.3	49.5	10.1	59.0
N21-1	9.8	16.3	5.7	40.4
FARO 15	10.2	26.7	10.9	36.2
Colombia 1	10.3	17.9	6.1	31.3
IR4625-132-1-2	10.6	9.2	2.9	29.6
IR2035-120-3	10.6	5.3	2.4	17.5
LAC 23 (white)	10.8	8.6	1.4	18.8

use in irrigation schemes, where total yields of 15 t/ha can be obtained from three croppings (NCRI 1978, 1979).

For the deep-water wetlands, cultivars producing yields of 3–5 t/ha have been identified, BKN 6986-38-1 being the most promising.

We have recently intensified work on development of cold-tolerant varieties for use where temperatures during November–January have prevented cultivation of a second crop of rice (Table 6). Other activities in varietal improvement are aimed at increasing tolerance to acidic soil and soils with toxic levels of iron and at

Table 8. Effect of date of seeding on grain yields (kg/ha) of three varieties of deep flooded rice.

Date of seeding	Yield (kg/ha)		
	FARO 14	Godalaki	IR442
30 May	1391	2977	4152
6 June	2429	2971	2248
13 June	2521	2742	3293
20 June	2977	3058	2977
27 June	2902	1726	2587
4 July	2248	3138	3058
11 July	1247	3213	3448
18 July	1590	1463	1500
25 July	772	1195	918
1 August[a]	0	0	0

[a]Seeds were planted but did not germinate because of flooding.

developing varieties with resistance to pests and diseases. For example, in recent studies to identify sources of resistance to gall midge, FAROX 233-7-1-1, FAROX 288-2-1-1, and FAROX 239-2-2-1 were identified as moderately resistant, with less than 2% infestation compared with up to 18% for other varieties (NCRI 1984). A highly significant relationship ($P < 0.01$) existed between the silica content of the rice plant and varietal resistance to the pests (Table 7).

NCRI scientists are working closely with their colleagues in universities as well as international organizations such as IITA, WARDA, and IRRI, testing materials in many locations as part of the coordinated rice evaluation trials (CRETs). Outstanding materials from these trials are tested on farms throughout the country by the National Accelerated Food Production Project (NAFPP) before being released to farmers.

CROP HUSBANDRY

The varietal improvement efforts are also supported by work on cultural practices. Time of planting studies, for instance, have been undertaken in various wetland areas. Results have indicated that direct seeding in deep-water wetlands should be done early in the rainy season between the first week of June and the middle of July (Table 8).

In shallow wetlands without irrigation or those with supplementary irrigation, farmers delay planting and take advantage of the photoperiod-sensitive varieties available. Results of work at Badeggi showed that planting between July and October gave the best yields (Table 8). Environmental conditions prevailing in the nursery during tillering and in the last 40 days before harvest determined yields (Fagade and Ayotade 1977), with solar radiation and sunshine hours being highly correlated with yields ($r^2 = 0.56$ and 0.76, respectively).

Although transplanting has been recommended for many years in Nigeria, particularly for areas with some water control (FDAR 1962), experiments have shown that transplanting is not significantly superior to direct seeding for short-duration varieties, particularly when costs are considered (Table 9).

Early recommendations were that seedlings be transplanted at 4 weeks after seeding (FDAR 1962), but farmers often delay the operation until much later. Recent studies have shown that short-duration varieties, if transplanted later than 30 days after seeding, have significantly reduced grain yields. In contrast, long-duration varieties can be transplanted as late as 56 days after seeding without significant reductions in grain yields (NCRI 1978).

Also, optimal yields depend on spacing: lodging varieties have

Table 9. Effects of method of planting on grain yields of rice planted at Badeggi, Nigeria, 1975–77.

VARIETY/ planting method	Grain yield (kg/ha)			
	1975	1976	1977	Mean
FARO 15				
Control (transplanted on wet bed)	5388	4266	3551	4402
Broadcast on dry seedbed	3196	3020	2982	3067
Drilled on dry seedbed	3084	3867	2594	3182
Dibble planted on dry seedbed	2466	3742	3639	3282
Broadcast progressively on wet bed	3557	2232	3086	2958
Drilled progressively on wet bed	3797	3458	2579	3278
Broadcast progressively in water	3155	2631	2426	2737
FARO 13-21				
Control (transplanted on wet bed)	2362	2856	3841	3020
Broadcast on dry seedbed	2011	2801	2451	2421
Drilled on dry seedbed	2191	2739	2126	2685
Dibble planted on dry seedbed	1525	2495	3821	2614
Broadcast progressively on wet bed	2762	1990	2698	2483
Drilled progressively on wet bed	1392	2216	2013	1874
Broadcast progressively in water	3668	2701	2327	2897
FARO 8				
Control (transplanted on wet bed)	3663	3599	2918	3393
Broadcast on dry seedbed	1903	1454	2204	1854
Drilled on dry seedbed	2390	2096	2748	2411
Dibble planted on dry seedbed	1730	2034	3214	2326
Broadcast progressively on wet bed	1434	1662	2241	1779
Drilled progressively on wet bed	1637	2639	2094	2123
Broadcast progressively in water	2192	2112	1914	2073

performed best when transplanted at wide spacings (25 × 25 cm), whereas the nonlodging varieties produced highest grain yields when transplanted 10 × 10 cm apart (Fagade and Ojo 1977).

Crop protection is crucial once the plants are established. Akinsola (1975) found that stem borers and gall midge are the major rice pests in the wetlands. Pesticides such as lindane, diazinon, and birlane have been found effective for control of lepidopterous borers and *Diopsis* (Akinsola 1975; NCRI 1982, 1983, 1984).

At present, however, weeds, not insects or diseases, are the most limiting factor for yields in areas where soils and water are not constraints (Akobundu and Fagade 1978). When weeds are not controlled, losses of up to 100% are recorded. Weed control in farmers' fields in the country is often inadequate because of costs and timing of weeding. Efforts at evolving effective and cheap methods of weed control have shown that good land preparation can limit weed competition.

After crop establishment, two weedings by hand within 14-40 days after seeding or transplanting in wetland rice have been shown to be adequate for weed control but can be quite costly because of labour requirements.

Herbicides are often cheaper than hand weeding and just as effective in wetland rice cultivation; for example nitrofen, bentazon, oxidiazon, and thiobencarb, or combinations of these have been shown to kill a wide spectrum of weed species without causing reductions in rice yields (NCRI 1983).

The major diseases of wetland rice are blast, caused by *Pyricularia oryzae*, and brown spot, caused by *Helminthosporium oryzae* (Awoderu 1972, 1974). Considerable work has been done on the biology and control of these diseases (Aluko 1970), and blast-resistant varieties such as FARO 16 and 18 are now available. Other diseases that were minor in the past such as rice yellow mottle virus (Rossel et al. 1982a) and leaf scald (NCRI 1984) are becoming widespread.

RICE-BASED CROPPING SYSTEMS

To supplement practices that increase yields from a single crop, some farmers have begun to grow a second crop each season. In fact some areas in Nigeria are suitable for three or even four crops annually. Although research on rice-based cropping systems has just recently been given priority, preliminary studies of multiple rice cropping have indicated that in selected locations yields from continuous cropping could be 10-15 t/ha compared with 2-4 t/ha with local traditional practices of only one crop annually.

The growing of upland crops before or after rice is also being studied in some climates and soils. For example, in 1983, Sinner et al. reported that two crops of early maturing rice, grown in 227 days at

Table 10. Yields in a rice-based cropping system in a rainfed lowland area (Badeggi), Nigeria, 1977-78 (Ayotade 1979).

	Upland rice (cv OS 6), rainfed	Lowland rice (cv IR30), irrigated	Cowpea (Ife Brown)	
			mulched	unmulched
Date direct seeded	6 May 77	—	17 Jan	17 Jan 78
Date seeded in nursery	—	21 Sep 77	—	—
Date transplanted	—	10 Oct 77	—	—
Date harvested	7 Sep 77	8 Jan 78	31 Mar	31 Mar 78
Maturation (days)	122	110	74	74
Grain yield (t/ha)	3.8	4.6	0.8	0.5

Badeggi, gave a combined yield of 8.4 t/ha and a third crop of dry-season cowpea could be grown on residual soil moisture (Table 10).

MILLING QUALITY

The increases in production are coming at a particularly opportune time in Nigeria because imports have been cut and demand is growing.

Nigerian consumers have been shown to prefer parboiled rice, but the process of parboiling and milling employed by the farmers leads to breakage and an unattractive product. Improved methods of parboiling that involve soaking in hot water at 70°C for 5-6 h (the time depending on the variety) and then steaming for 10-15 min have been developed. Also, studies on the physicochemical and cooking qualities have been carried out (Adeyemi et al. 1982).

Factors such as variety, fertilizer, spacing, etc. affect the milling quality of rice and have been extensively studied. While applications of N have been shown to increase the recovery rates of chalky FARO 13 (IR8), they had no effect on two nonchalky varieties FARO 8 and FARO 12 (Fagade and Ojo 1977). Competition for plant nutrients at high densities limits head rice returns.

CONCLUSIONS

Considerable progress has been made in wetland rice research, but even greater efforts than have been applied to date are needed in:

- Breeding adaptable, high-yielding varieties for the various wetland ecologies; for example, cold tolerance in mid and high altitudes and tolerance to salinity for large tracts of inland and mangrove swamps;
- Study of water-soil-plant relationships in rainfed and irrigated rice;
- Rice-based cropping systems that permit more efficient land use; and
- Development and testing of methods of land preparation and weed control.

Transfer of new technology to smallholders: experience from Nigeria

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Abstract *About 45% of the total rice produced in Nigeria is from inland valley swamps. The Bida Agricultural Development Project (BADP), in Niger State, Nigeria, was established in 1980 to boost production in an estimated 60 000 ha. Of this area, inland valley swamps (fadamas) constitute 67%. BADP's swamp-improvement program has been heartily received by farmers, with improvements being mainly in water control and management. To date, about 3500 smallholder rice farmers have benefited from improved swamplands on 3230 ha. With improved swamp conditions, farmers have been able to raise rice yields from 1.5 t/ha to 2.0 t/ha on small schemes and from 2.2 t/ha to 2.8 t/ha on larger schemes. Farmers have also responded favourably to the introduction of new technologies, such as new crop varieties, harvesting and processing approaches. Generally, major constraints have been lack of training opportunities, technical inputs, and appropriate tools as well as the slow pace of extension research and fluctuations in the price of rice. Although no serious health problems have arisen as a result of swamp development, BADP staff, in collaboration with the Niger State ministry of health, have initiated both preventive and curative measures for control of schistosomiasis.*

The Bida Agricultural Development Project (BADP) was established in 1980 and funded by Niger State, the federal government of Nigeria, and the World Bank. The project was set up to last for 5 years, with the prime objectives being to increase agricultural production by 25% and to raise farmers' incomes. The project was to provide farm inputs, such as fertilizers, improved seeds, credit, tractor-hire services, extension support as well as infrastructure, such as feeder roads, service centres, and low-cost irrigation schemes.

Located in southern Niger State (the middle-belt of the country), the project constitutes about one-third of the state and covers an estimated 17 000 km^2 (1.7 Mha) making it the largest of the six projects being sponsored by the joint program. About 41% of the state's population (about 1.9 million) is found in the project area. The vegetation is typical of southern guinea savanna, the average annual rainfall being about 1300 mm and occurring during 7 months (April–October). The Niger river is the southern boundary, providing along with its two major tributaries (Kaduna and Gbako rivers), 60 000 ha, of which 67% is inland valleys — fadamas — suitable for rice cultivation.

FADAMA DEVELOPMENT

Many farmers are already making their living on the fadamas either through crop production or through fishing (about 8% of farmers in the project area derive primary income from fishing). By introducing water control, bringing more areas under irrigation, providing better techniques for rice and other crops suitable for fadama production, project planners hoped to improve the agricultural practices at relatively low cost.

The fadamas being developed within the project are 2–150 ha, with the average being about 20 ha. When a community requests assistance from BADP to develop its fadama or when project personnel identify a fadama with great potential and obtain support from the village heads, work begins.

An irrigation officer visits the fadama to assess its potential, considering land ownership, size and nature of the catchment area, existing streams, water conditions, soil type, crops grown, estimated area of the swamp to be improved and future possible expansion, site for the head dike construction, etc. He or she can then decide whether BADP should assist in developing the scheme and inform the community of the decision.

By and large, the scheme is self-help by the farmers, with guidance from BADP. The main features of the water-control system are (Savvides 1981):

- A head dike constructed across the swamp, along the upper reaches of the stream so that the water can be diverted into canals. The size of the head dike is calculated from expected peaks in flow of the stream. BADP usually provides expertise and some of the initial materials (gravel, cement, stones) for construction, while the farmers supply labour and other construction tools. Spillways with wooden gates regulate the flow of water.

- Main canals, excavated along the periphery of the swamp and at elevations higher than the area to be irrigated. In the large swamps, secondary and field canals are usually constructed. The farmers excavate canals; they are supervised by irrigation staff who show them how to use simple tools such as poles and tapes or ropes to mark out the depth and width of the canal along the alignment, which is determined by a leveling instrument.
- Canal gates constructed of concrete (if possible, cast on site) with vertical grooves 2 × 2 in (ca 5 × 5 cm) between which a plank of hardwood can be slid as a gate. Usually the dam is 0.7 m above the bed level of the canal.
- An embankment (for head dike and canal) earth-filled, usually constructed on both sides of the head dike and on one side of the canal to hold up water. Medium to slightly heavy soils are used and compacted well, either by a mechanical compactor or a hand rammer, to withstand the pressure of water. Farmers are usually actively involved in putting up the embankment.
- Pipe outlets installed every 20–30 m to drain the water from the canals into the paddies. Two sizes of polyvinylchloride pipes (63 and 90 mm diameter) are used, depending on the capacity of the canals. During installation, the pipes are placed horizontally or sloping slightly toward the rice plots.
- A main drain (floodway), constructed to remove excess water during high floods and also to drain outflow water from the paddies. In most cases, the natural water course serves as the main drain. Drains, generally, may serve a dual purpose of collecting water from the upper paddies and supplying the same to the lower paddies.

The materials and labour for a water-control system in a typical fadama, consisting of these main features in 1980-81 cost BADP about NGN (Nigerian naira) 329/ha. In 1983-84, the cost was about NGN 400/ha, including the cost of labour, materials, fuel, equipment and machinery, amortization of vehicles, and salaries of permanent staff.

FARMERS' RESPONSE

The farmers usually turn out in large numbers to construct the irrigation system.

To date, BADP has dealt with 120 villages with an estimated developed area of 3230 ha, involving more than 3500 smallholders. The crop is mainly rice, but cowpeas, sugarcane, and vegetables are being introduced during the dry months (November-March) under supplementary irrigation (wherever possible) and residual soil moisture. Crops such as bananas and oil palms have already become a permanent feature.

Generally, these swamps, which flood during the rainy season, dry out during the dry months of the year and water flow stops by December.

Close to 90% of all farmers involved in swamp cultivation also farm uplands where they grow, in mixtures, a variety of crops such as sorghum, millet, cowpeas, bitter melon, maize, cassava, yams, and sweet potatoes. Swamp farm size per household (for swamp farmers) varies between 0.5 ha and 2.0 ha, averaging about 1.0 ha, while upland farms range from 1.0 ha to 5.0 ha with an average of 1.5 ha.

IMPROVED HEALTH

Recognizing that water-borne diseases were a real threat in these schemes, personnel in BADP decided to set up a small health unit as early as March 1981. This unit began assessing the prevalence and distribution of schistosomiasis as the major hazard.

The project staff invited the ministry of health of Niger State to collaborate and to assist with the preventive as well as curative measures. Several sample surveys were carried out to collect urine and stool samples for examination. Two species of parasite were identified — *Schistosoma haematobium* and *S. mansoni*. The former infects the bladder system and the ova escape from the body in the urine. The latter (*S. mansoni*) infects the portal system and the ova pass out of the body with the stool. Snails were collected around the fadamas to localize the hosts and, if possible, to identify habitat preferences of the species responsible for spreading the disease. Also, a sociological survey was undertaken to help identify groups who were vulnerable to the disease owing to their local conditions or general activities.

These surveys covered village areas where

- Irrigation schemes are already in place;
- Fadamas are going to be developed; and
- No irrigation scheme is being contemplated.

The sites were chosen to give a fair spread across the project area.

The prevalences have been low — 3.2% for *S. haematobium* and 4.1% for *S. mansoni* across the project area. In certain places, however, both species were found to be endemic, with prevalences as high as 40-60%. Some of these places were predictable, such as along the River Niger, but less so away from the floodplains. In irrigation schemes, the snails that act as an intermediate host for *S. mansoni* were found more regularly than the hosts for *S. haematobium* in the stagnant or slow moving waters of small pools in streams or in tertiary field canals. The intermediate hosts were common in schemes where water was permanent or the area was particularly low-lying and the water table close to the surface. On many of the fadama schemes, however, none of the intermediate species or other snail species were found, probably indicating that the dry season is a natural control.

The age and the size of schemes were not correlated with presence of the disease; however, in villages with an irrigation scheme and where schistosomiasis was found, farmers were infected with *S. mansoni* more often than any other occupational group. This finding no doubt reflects the length of time these farmers spend on the fadamas attending their crops.

People often did not know they had the disease and therefore probably continued to spread it. In at least one village, the disease was introduced into the local water through one or two farmers who had been working on a large fadama farther away from the village where *S. mansoni* had been found. Efforts were made first of all to heighten farmers' awareness of the disease and its mode of spread. Films were shown to emphasize the dangers of defecation and urination in streams and swamps. In some stream areas, the village communities were encouraged to reduce all vegetation, terrestrial and aquatic, to an absolute minimum, to reduce the favourable habitats of the snails and also to increase water flow in streams and canals in these swamps. BADP staff, along with the rural health clinics, are currently administering drugs purchased by the project to people who have been infected.

The project does not seem to have created any buildup of *Schistosoma* sp. on developed fadama schemes, although it may have escalated the spread in areas where the disease was already present. BADP personnel are optimistic that with the continued cooperation of the state ministry of health, such problems will be contained.

TECHNOLOGY

Farmers have picked up the techniques and have increased total land under cultivation by at least 20% and rice yields from about 1.5 t/ha to about 2.0 t/ha, especially under improved water management and fertilizer application. On the large fadamas of the river floodplain, yields have been increased from about 2.2 t/ha under the traditional system to about 2.8 t/ha under the improved system.

A survey by BADP staff showed that most of the so-called local rice varieties are a mixture of local and improved varieties, in particular ITA 212, which is well accepted by farmers for its grain colour and size as well as its tillering ability.

Harvesting practices by farmers on the improved fadamas are still traditional. Blunt sickle is normally used to cut the whole rice plant about 15-20 cm from the ground. The stalks are made into sheaves and then stacked (heads inward) in a circle on an elevated portion of the fadama. The sheaves are left to dry before being threshed. To speed up harvesting, IITA collaborated with BADP staff to test a serrated-edged sickle. The farmers preferred the serrated sickle so the project has acquired about 500 for sale to farmers for use during the 1985 harvesting season.

To thresh rice, farmers usually beat the sheaves in a shallow hole dug on the elevated portion of the fadama, around which the sheaves have already been stacked. This method, however, causes dirt and stones to get into the threshed paddy. As an alternative IITA developed a threshing drum that is easy to operate and enables the farmers to obtain clean seeds from the fadama. Drying floors, made of cement or local materials have also been introduced: to date about 150 drying floors have been constructed in about 20 villages in the project area.

Short-season cowpeas (ITA 60 and TVx 3236) have also been introduced to farmers on the fadama schemes. On residual soil moisture, these cowpeas yield about 600-700 kg/ha, with two sprayings, and have been quite attractive to farmers. For comparison, main season cowpea yields of 800-1200 kg/ha are being obtained by the same and other farmers.

MAJOR CONSTRAINTS

Although modest gains have been made with the introduction of some improved packages to smallholders, progress is constrained by:

- The training that is needed by farmers so they can adopt the new techniques;
- The lack of inputs that farmers need to carry out an improved plan of action or to apply an improved package;
- Lack of appropriate tools and implements and crop varieties suitable for the smallholder;
- The slow pace of extension research on swamp-rice cultivation by smallholders;
- The costs of inputs and fluctuations in prices that reduce farmers' determination to adopt new and improved packages.

Approaches to development of the wetlands: projects in Nigeria

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Abstract *Nigeria's national and state governments have launched several agricultural projects that aim at installing irrigation systems and increasing crop production from the wetlands. The incentives and approaches differ among the projects, as do the involvement of local farmers and the level of adoption of the recommended techniques. A look at the projects undertaken by the river basin development authorities and others in Lafia, Bida, and Kano provides some insights into the advantages and disadvantages of different approaches.*

By the year 1990, Nigeria will need 1.91 Mt of rice yearly to feed its people at the present rate of consumption (20 kg/head). To be self-sufficient at that time, the country must raise production by 20% annually (Idachaba et al. 1985) (Table 1). This growth rate is possible (Awoyemi and Idachaba 1985) but requires sustained development with improved varieties and agrotechniques as well as cultivation in new areas in southern Nigeria and new and abandoned fadamas in northern Nigeria.

In the past in Nigeria, rice was a food for feasts or festivals, but with increased income and urbanization, the demand for rice has increased from grams to kilograms. The federal government has embarked on several schemes to boost local production, including the Green Revolution, Operation Feed the Nation, and the Special Rice Scheme (Nanda and Chaudhary 1985). The impact, however, has been minimal. In the meantime, the 19 state ministries of agriculture, 11 river basin development authorities (RBDAs), and agricultural development projects (ADPs) — 10 ongoing and 10 others in various stages — started their own programs for rice development and production.

They focused mainly on small- and medium-scale rice farmers,

Table 1. Projected rice demand and supply in Nigeria, 1985–90, at current rates of consumption (20 kg/person) and population growth (2.63%/year), and rice production at potential growth rates of 3.5%, 10%, 20%, and 30%.

Year	Population (10^6)	Rice demand at 20 kg/head (10^6 t)	Production potential (10^6 t) at growth rates (%) of:			
			3.5	10.0	20.0	30.0
1985	84.00	1.68	0.83	0.88	0.96	1.04
1986	86.18	1.72	0.86	0.97	1.15	1.35
1987	88.42	1.76	0.89	1.06	1.38	1.76
1988	90.72	1.81	0.92	1.17	1.66	2.28
1989	93.08	1.86	0.95	1.29	1.99	2.97
1990	95.50	1.91	0.98	1.42	2.39	3.86

providing inputs and other production support through extension. Although the projects are still being refined, some comparisons in approach can be made.

Some projects focus on a commodity, with public policy and resource allocation devoted directly to increasing production of that commodity. Special rice programs in Bida, Lafia, Gusau, Ayangba, and Ilorin funded by the Federal Department of Rural Development and the World Bank are examples. The targets in such projects are well defined so that inputs and energy of the staff are all geared toward increased production of a specific crop. It is an effective model, but its success depends on adequate funding, timely supply of funds and inputs, firm commitment by officials and staff. The commodity approach, in which rice would be practically continuously cropped, was suggested by Idachaba (1985) for a successful food program.

Many projects that are currently focusing on land development could promote rice production. In general, however, they are attempting to cover the agricultural spectrum of crops being grown in particular areas.

RBDA PROJECTS

The river basin development authorities focus on irrigation as part of land development. They normally do not charge for water development. They allocate the land to farmers and provide technical support as well as land preparation, for which a fee is charged. Irrigation water is supplied according to need, and the farmers pay for whatever they use. At harvest, the authorities help in marketing the produce.

Productivity is high and stable in such projects. As the RBDAs do not go into direct production, they must draw on small and medium-scale farmers already in an area. Thus, they are not suitable for areas with only a few farmers.

There are no agrotechnical constraints to this model, but the farmers learn little because RBDA handles many of the agricultural activities as well as the provision of water. If RBDAs transferred some of these responsibilities to ADPs or functioned on a demand basis, the model would be improved in our opinion. The projects initially require heavy investment of capital but can become economic in the long run.

LAFIA PROJECT

Land preparation, fertilization, sowing, harvesting, and threshing are done by project staff in the Lafia project funded by FDRD and World Bank. After sowing, the staff allocate 5-ha portions to groups of 10 farmers who do spraying, top dressing, weeding and other cultural operations. All the inputs are provided by the project. After the grain is threshed, 30-40% of the produce is provided to the farmers as payment for the labour.

In this model, large areas can be cultivated, and the productivity level is usually high. The benefits are reaped by both the farmers and the project. As the areas of cultivation are large and contiguous, these operations can introduce effective measures to control pests such as birds, rodents, etc. and offer employment opportunities for local people. The greatest disadvantage is that the activities cannot be sustained without the project. If the support services are withdrawn, the operations collapse.

Another disadvantage is that the farmers are not committed to the project as the project pays for all the inputs and the farmers receive a type of payment for their labour. Recently, a registration fee of NGN (Nigerian naira) 70/team has been introduced. This fee is returned if productivity exceeds 2 t/ha. By including this risk factor, the project staff have improved the level of crop care by the farmers.

Weeds have proved to be a major constraint in the Lafia project: preemergence herbicides are needed for application just after sowing when the field is suitable for tractor-mounted sprayings. Also, project personnel need information on managing and operating large-scale farms as well as tractors and implements for land preparation and sowing in muddy and flooded conditions.

KANO PROJECT

In Kano, two diverse approaches are used to promote the goal of increasing rice production. In one approach, fadamas that used to be flooded through natural inundation from neighbouring rivers are being rehabilitated. Old inlets are dredged and earth is used to direct nearby rivers to the inlets. The costs are minimal. Once the fadamas are flooded, farmers come to crop and obtain, at cost, seed, fertilizers, and a package of practices. They pay nothing for the water. The fadamas where this approach can be applied must have good soil and enough farmers in the vicinity to undertake cultivation without much support from the agency. The second approach is being undertaken in shallow fadamas that cannot be flooded long enough for a rice crop. Irrigation — water pumped from tube wells or nearby rivers — augments the local rainfall or flooding. The tube wells and pumps are provided by the agency at cost. Since the area of each operation is small, say 1 ha, farmers provide the labour for cultivation. In the dry season, vegetables or other crops that provide high cash returns are grown. This model has excellent potential in areas where rainfall is low and erratic but soil is good, aquifers are exploitable, and farmers are plentiful.

Depending on the area, both rich and poor farmers can be supported. The capital investment and initial expenses are minimal and can usually be recovered by control over the water. Yields are high, and the farmers can be offered a good price for their produce in government procurement programs.

In the flooded fadamas, the water level is variable so farmers need rice varieties that yield well under those conditions and various photoperiods. They also need efficient measures to control stem borers and aquatic weeds, particularly the difficult ones like *Oryza longistaminata*, for which there is no effective herbicide. Machines and implements for land preparation under flooded conditions are also needed as is more secure land tenure.

BIDA PROJECTS

The Bida projects are an extension of the model applied in Lafia. The community land is prepared by the ADP, allotted to a group of farmers in the same area. The operations of weeding, herbicide application, top dressing, crop care, bird watching, harvesting, and threshing are done by the farmers with advice from extension agents. The produce is divided into three parts — one is retained for development cost deposited in a bank, another is for next year's input, and the last is shared by the farmers.

Plus points of this application are:

- Cooperative farms allow for a large number of farmers to be trained effectively, as all operations are performed in front of the farmers in a recommended way.

- Extension agents can work with a group rather than individuals and the rate of adoption is high.
- Because of the individual's involvement, the crop is well tended.
- Farmers use collective bargaining power in selling and thus get an appropriate price for their produce.
- The produce is not pilfered by the participants, as it is in enterprises of the same order owned by the state or by companies.

The application is limited by the amount of land one person can prepare with a hoe. In most parts of the Kaduna and Niger floodplains, farmers can cultivate two rice crops yearly but at present are growing only one because of insufficient labour. Upland crops in most of the areas receive priority. Only after sowing and weeding upland crops do farmers come to prepare the land for rice and may not transplant the crop before the first week of October. (Rains are reliable in the area by the first week of June.) From June to September, short-duration rice could easily be grown if some of the operations were mechanized. Some possibilities that need research are whether the conventional setup for tractor hire can be improved; whether private ownership of tractors should be promoted; whether animal power is suitable in the area; and how to modify conventional tractors for use in the soft, wet soils.

Another approach is used in Bida where irrigation is needed. The land and irrigation system are developed by ADP using simple diversion dams and canals. The farmers pay small fees for the water and for inputs that are accompanied by recommendations on use. This application, though similar to the RBDA model, is cheap and cost effective and is particularly suitable for flat fadamas where river water can be diverted.

The constraints in the Bida projects are the lack of:

- Suitable varieties — early to late, drought tolerant to submergent tolerant;
- Farm power and implements, particularly for land preparation; and
- Information on suitable plant populations and cultural practices.

Because of the lack of information on suitable cultural practices, the farmers plant on the ridges at about 50% of densities recommended elsewhere. The reasons given for ridge farming are ease of land preparation; weeding by hoe and burial of weeds, along with some soil chips from the ridge, in the furrow; plant protection from iron toxicity; and suitability for direct seeding even when water stands in the furrows.

LARGE-SCALE PRIVATE ENTERPRISES

A few large-scale, mechanized efforts are under way in the country and more could be established. They produce large quantities of rice without much labour, since land preparation, sowing, harvesting, and threshing are all done mechanically. The model is ideal for areas where labour is scarce; the government policy is stable; machinery and maintenance are available.

Constraints are the lack of:

- Implements suitable for puddling (cage wheels or other kinds of modifications for tractors to enable them to work in muddy conditions);
- Herbicides, primarily preemergence types that can be applied just after direct seeding;
- Fertilizer formulations that eliminate top dressing;
- Machines and methods that can clear the fields without damaging the topsoil;
- Information on agronomically feasible field sizes and gradients;
- Machines for uprooting and transplanting seedlings;
- A technique for direct seeding in water; and
- Information on timing of operations in rice cultivation.

Table 2. Present and potential areas for rice production in Nigeria.

	Rice-production area ('000s ha)	
State	Potential	Present
Abuja	—	2.40
Anambra	88.88	21.00
Bauchi	332.90	32.41
Bendel	188.44	40.00
Benue	255.94	83.97
Borno	581.03	52.00
Cross River	135.19	17.39
Gongola	457.47	56.50
Imo	61.03	11.93
Kaduna	351.09	34.97
Kano	216.34	18.00
Kwara	334.22	39.54
Lagos	16.72	0.73
Niger	325.06	40.40
Ogun	83.78	7.00
Ondo	104.76	18.00
Oyo	188.46	10.23
Plateau	290.04	35.00
Rivers	96.73	2.53
Sokoto	512.48	26.00

Wetland farmers in Africa with their hoes.

CHOOSING A SUITABLE PROJECT MODEL

Where labour is scarce, mechanization appears to be the only choice. Compared with manual operations that require 800+ h/ha, mechanized rice cultivation can be undertaken in 20–30 h/ha (Rutger and Grant 1980). Studies have indicated that energy consumption increases by 26% in mechanical land preparation and threshing (Kuether and Duff 1979), but the timeliness of the operation, quality of land preparation, size of area, and increased yield offset additional inputs.

Nevertheless, much of the production will continue to be by smallholders, with the Lafia, Kano, and Bida models being well suited to Nigeria at present. They incorporate an element of social justice that is absent in large operations (Table 2).

Irrigated fadamas have potentially high and stable yields where the RBDA and Kano models can be extended. Two crops of rice yearly are possible in states where predominantly upland rice is cultivated (rainfall spreads from April to September, with a lull in August in certain areas).

CONCLUSIONS

Taking a commodity-oriented approach for rice has specific advantages in Nigeria at present because of increased demand and

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high potential for cultivation. We suggest combining the type of project used in Kano with a commodity orientation. The pace of progress in Lafia, Kano, and Bida, although slow to moderate, is characterized by overall improvement in the cropping system. The farmers within these projects are primarily smallholders and therefore represent most of the farming community. The RBDA model has limited scope as it emphasizes land development and irrigation instead of agricultural production.

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Integrated development of watersheds in Sierra Leone

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Abstract *Any plan to develop the swamplands of Sierra Leone must take into consideration the watershed of the adjacent uplands, which increasingly are being cleared for cultivation and eroded by the heavy rainfall. The swamplands are part of the ecologic system not the whole system, and to most farmers in Sierra Leone they are much less attractive than the uplands for cultivation. The reasons include the arduous tasks of land preparation and weed control, the limited repertoire of crops they can support, the health hazards, and the low prices associated with the main produce — swamp rice. Thus, the uplands will continue to be denuded while swamplands remain undeveloped, the danger being that eventually the whole country will be a swamp unless the government takes a holistic approach to development.*

The lowlands of Sierra Leone are mainly composed of vast, varied swamps, many of which are still to be classified. Broadly, they can be categorized as inland valley swamps (1819 km^2), mangrove swamps (1717 km^2), and others (643 km^2). Of the total, about 1100 km^2 are considered to be cultivable (Gordon et al. 1979).

At present, rice cultivation in the swamps yields about 130 000–150 000 t annually. For comparison, upland rice production is about 250 000–380 000 t/year and the per-person intake of milled rice is about 115–130 kg/year (a total consumption of 760 000 t/year). In fact, rice constitutes almost 90% of the energy intake of an adult Sierra Leonean.

The potential production from the swamps is 6–8 times the current value. The levels could be raised by increasing the area under production or by improving the management of areas already being cultivated. The constraints to either approach are substantial —

shortages of labour, technical know-how, machinery, fertilizers, crop-protection services, improved planting materials, and infrastructure.

BACKGROUND

Upland farming in Sierra Leone, as in most West African countries, has always been more popular than entering a swamp to clear the land; to construct bunds, drainage canals and outlets; and to plow or dig and level the cleared land. The work involved in developing the swamp could well take more than one season, without any visible results in terms of rice output. The farmer could do all this work, just to discover that drainage water would not run off or that the stagnant water contained iron levels toxic to the rice. In the process, he or she ends up feeling weak and ill from the undeniable health hazards found in the swamps. In the next season, the entire area could be infested with unbeatable weeds and insurmountable maintenance. So what went wrong?

Farmers in Sierra Leone are accustomed to clearing a piece of land — upland or swamp — by slashing and burning the vegetation, the "Citamene" system. They clear no more land than is required for that year's cultivation because after harvest they leave the land fallow to regain its fertility.

Multiple cropping is popular, with the cultivated area becoming the farmers' local supermarket. Only in a limited way do these traditions apply to farming in swamplands. When a relatively small area of a swamp has been cleared for cultivation by traditional methods, the area immediately becomes flooded — more suited to aquaculture than agriculture.

The soils of the swamplands are hard to till, especially with a hand hoe. When wet, they are sticky and when dry, hard. The cleared land receives ample light for weeds to grow rapidly and even to propagate selective, hardier species.

The conditions in the swamps restrict the crops that can be grown, with cultivation of paddy rice being the main choice. So, while the farmer is busy growing a mixture of crops on uplands, the weeds grow in the swamp and make it almost impossible to cope with both types of farming at the same time.

For these reasons, about 50% of the arable uplands in the country are currently being cultivated, whereas the value for swamplands is only 10% (Gordon et al. 1979). Nevertheless, interest in swamp rice cultivation is growing because of the pressure on the uplands and diminishing returns from traditional methods as fallow periods are progressively reduced.

WHAT CAN BE DONE

Field demonstrations and projects have all clearly indicated that development efforts must incorporate:

- The identification and classification of the swamp ecologies;
- Methods that can cope with the amount of work involved in land preparation and management of the swamplands;
- Organization that can direct development resources of areas far larger than the small plot a farmer can manage to develop;
- Total water control;
- Appropriate techniques that keep the rice growing under controlled conditions; and
- Maintenance procedures that can sustain the system irrespective of floods that cannot be avoided but can be averted.

Already numerous patches of well-developed swamplands can be seen in the country; they include ditches and bunds and are examples of a well-maintained system of rice cultivation. However small, they clearly show that the virgin swamps, which are highly fertile, can be developed for rice production, especially with the increasing choice of rice varieties as a result of breeding efforts in the country. They exist because of a combination of local experience and imports of know-how and financing. Notably, Chinese expertise has contributed.

The impetus has grown as a reflection of experience gained, and the interest of the government is being aroused. Farmers have been able to participate in swamp development, investing money and labour into a seemingly risky venture especially when judged by the past.

The swamp areas that were once developed but later abandoned attest to the risks. One major reason they failed is the unexpected, persistent dominance of weeds in the swamps. Farmers, with their limited tools and equipment, have failed to cope and development planners have failed to ensure that the farmers have the technical means (cultural practices, tools, fertilizers, know-how) to maintain the projects.

One can easily find multiple reasons for failure in swamp development and swamp rice cultivation. Some are obvious and others obscure — most reflect an inadequate knowledge or consideration of:

- The hydrologic conditions of an area (data are often hard to get or not available and long-term studies are beyond the scope of the projects);
- Long-term implications of swamp development (projects are usually focused on short-term results);
- The effects of mechanized land preparation (the equipment

drastically changes the nature of the vegetation, whereby only weeds survive);

- The type and supply of tools suitable for maintenance of the developments;
- An appropriate cropping system (to date not one project has taken into account the complex conditions under which rice has to be grown in the swamps of Sierra Leone);
- The training of farmers (even the best-designed development project cannot be feasible without a massive training of farmers);
- The amount of work, knowledge, skills, and money required; and
- Local labour availability (other enterprises such as mining compete for labour resources during transplanting and harvesting).

Any attempt to intensify cultivation on a continuing basis should be made with the understanding that fertilizers are imperative, as are practices that minimize the amount of fertilizers used by ensuring minimal losses and maximal use of processes such as biological nitrogen fixation and animal manures wherever and whenever convenient. Maintenance of adequate levels of organic matter and reduction of nutrient loss may be achieved through efficient management of crop residues. Appropriate methods of land clearing, development, subsequent cropping, and soil management are determined by the prevailing ecologic and socioeconomic conditions and in particular the soil types and topography. Every swamp has its own ecologic balance. The vegetations differ from one location to another. Some are dominated by deep-rooted, branching or thorny species that are difficult to cut. Initially, an investigational track could be opened into the swamp just to verify the requirements for clearing. At any rate it is highly advisable to consult farmers experienced in bush clearing of a similar type of swamp.

LAND CLEARING AND PREPARATION

Developing a swamp may take 3-5 years or longer. Meanwhile farmers want a crop to compensate for their efforts. Even gaining access to a swamp often is difficult. One needs access roads not only for development but also for removal of the harvested crop. Thus, land acquisition becomes a problem. If an access road can be opened for multiple purposes, it may become permanent.

Clearing the trees, shrubs, and other unwanted vegetation in the swamp is hard work, even with efficient tools and heavy duty machinery. Pulleys and chains simplify the task of uprooting trees and scrubs but removing vegetation with branching root systems requires a piecemeal approach. Simple cutting and hacking with long-bladed knives are usually done, whereas cutting devices that take advantage of leverage, for example long-shafted branch cutters, would be useful.

We estimate that land clearance requires as many as 100 workdays/ha or as few as 20–30, depending on the characteristics of the vegetation. For comparison, the corresponding figures for the work to establish water control are 80–90 workdays/ha and 50–60 workdays/ha. In both instances only manual labour and simple hand tools are used.

Labour for such backbreaking work is a constraint; yet meaningful mechanization would require that the swamp be drained by ditches and canals and allowed to dry sufficiently to bear the weight of heavy equipment moving on broad support wheels with mudgrips. While such machines do exist, they are not available to ordinary farmers.

Ideally, land clearing should be followed quickly by land preparation so that regrowth of vegetation is minimized. Land clearing tends to stimulate selective growth of weeds, especially hard-to-eradicate grasses and sedges that suddenly find space and light to flourish. The third operation, destumping, can take place at leisure, although regrowth of stumps also takes place. Herbicides, besides being costly, are not advisable, because they contaminate the water and represent a health risk to those moving around in the swamp.

CULTIVATION

On newly cleared inland swamps, effective land preparation may not be possible. Simple broadcasting of paddy rice using a seed rate of 90–110 kg/ha has been recommended. To overcome the weed problem, farmers may direct seed on completely saturated soils (water 5–15 cm deep), a technique known as "flood seeding". The land is plowed at least once or twice beforehand, and the seed is pregerminated. The saturation to some extent keeps the weeds down, and the process, though wasteful of seeds, is labour saving.

The assumption is that some water control can be done. Bunds have to be constructed so that they are above the maximal flood level and made of material that will withstand seasonal flooding. Where the soil is sandy, the material for bunds will have to be imported to the site. Leveling the site protects against too rapid a flow; otherwise the water rapidly erodes and scours the sides of the bunds and canals.

MANGROVE SWAMPS

To establish effective flood control in the mangrove swamps may require the construction of an embankment, strong enough to withstand the tidal influx from the sea and to maintain freshwater at a given level. It also requires hinged one-way gates that open when freshwater is excessive but prevent the inflow of sea water. How many and where gates are required are engineering questions. The gates must be well maintained, as the saltwater corrodes them quickly.

Because of the acidic soils in the dry season, deep application of lime is beneficial, even though leaching occurs. Light application of lime, done during each cropping season, helps. The method is applicable to coastal areas where groundnut cultivation on residual moisture in the dry season is possible.

Heavy weed infestation, rodents, termites, and crabs all have been reported as problems of some magnitude. Soil types vary greatly, and site selection according to soil type is advisable. Direct seeding of pregerminated seed is worth trying, since flooding helps to control weeds. Some farmers transplant seedlings that are 40 or more days old because crabs can kill younger seedlings.

RIVERINE GRASSLANDS

Because of their location, the riverine grasslands are subjected to frequent flooding. Tall rice varieties or even floating rice are suitable crops, but the velocity of the rivers during flooding is high and can cause heavy damage to crops.

Establishing an effective flood control is economically infeasible. In the dry season, rivers could be used for irrigation, provided the perennial flow is adequate to irrigate the area. Vented dams can be used to divert the water into an irrigation canal. During floods, the gates are removed to allow the water to escape. They are composed of solid concrete pillars on a firm foundation with a spaced opening, 1-1.5 m wide, with slots, 5-7 cm thick, where wooden planks are inserted to hold the water back during floods.

BOLILAND SWAMPS

The boliland swamps are saucer-shaped so are difficult to drain but are large and represent substantial potential for rice cultivation. Applying the Indonesia method of terracing, i.e., broad ridging, is one means of elevating the cropped area and increasing the drainage. It does, however, require considerable development work. Once the broad ridges are installed, they are quite durable. Turfing of the sides of the slope reduces maintenance.

After being ridged, boliland resembles uplands more than swamps during the dry season so at that time of year is suitable for cultivation of upland crops.

OPERATION AND MAINTENANCE

Once irrigation and drainage are installed, farmers can grow successive crops of paddy rice or can alternate rice and upland crops, depending on the setup. The system is maintained by:

- Reconstruction and restoration of bunds;
- Patching with clay any sources of seepage along the banks;
- Monitoring of the outlets and level of water on the field; and
- Regular weeding of canals.

COST-BENEFIT

Swamp development requires substantial support from the government, i.e., a national interest rather than a private venture. Countries taking up swamp development need to draw on experts and obtain financial support for a complete hydrologic and groundwater development, not only for rice growing but also for inland fish farming.

For any development project, the sum of the tangible and intangible benefits must justify the costs. Since socioeconomic returns are intangible, a shadow price can be attached. What the ratio should be is arbitrarily fixed. For instance, we have found that costs and outputs from cultivation of swamp rice with inputs of high technology are not attractive economically at current prices in Sierra Leone. In contrast, we have found that at levels of input of low technology, cultivation of swamp rice is profitable (1.7) despite low yields.

Developing the swamplands, however, cannot be done in isolation. The swamplands are part of the ecologic system not the whole ecologic system. Managing them as separate from the uplands is courting disaster. As more of the uplands are constantly being cleared for cultivation, erosion and flooding increase, especially in a country like Sierra Leone where the slopes are steep. Clearing the forest vegetation has an impact on the groundwater as well as the topsoil. Under forest vegetation, part of the rainfall is intercepted by leaves and roots and subsequently returned to the atmosphere by evapotranspiration. Evapotranspiration diminishes when the forest vegetation is cleared and replaced by crops with a lower degree of interception or a short growing season as in the case of annuals. Such changes allow more water to reach the low-lying areas, and the water table there will rise. Springs in adjacent valleys, which are seasonal before clearing, become perennial afterwards.

AGROFORESTRY

Agroforestry — growing woody perennials (trees, shrubs, palms, bamboo, leucaena, etc.) with annual crops like yams, maize, etc. — is, in our opinion, the only means of ensuring that the entire country does not become swampland. It is a type of integrated land use particularly suited for marginal areas and low-input systems, such as slopes of 5% or more, common along the Freetown peninsula and in northern and eastern Sierra Leone. The objective and rationale of most agroforestry systems are to optimize the interactions between the woody component and the crop and animal components to improve the total quantity, diversity, and sustainability of production.

Traditional fallow trees and shrubs can be used to recycle nutrients and provide structural materials for staking, buildings, etc. One of the most promising agroforestry techniques, widely applicable, is hedgerow planting of woody perennials with annual crops being grown in spaces or alleys between the hedgerows. The woody species are pruned periodically during the growing season to prevent shading of the annual crops and to provide green manure. This form of alley cropping, developed at IITA, has been used in the production of maize and yams and promises to reduce fallow, perhaps to eliminate it, thus increasing the land available to the farmer. It also considerably reduces the cost of staking in yam production.

In combination with such an integrated approach to land development, swamps could be cultivated for rice, but for farmers to be strongly motivated to undertake the work, their investment and production must prove profitable, for example, through a more competitive price for swamp rice.

The potential for growing two crops of rice in the swamp is quite good, and recorded yields of swamp rice are encouraging. Indeed, quite a number of farmers in Sierra Leone have successfully cultivated swamps with little investment.

How sophisticated the approach to future swamp development should be depends on the financial resources available — a reflection of the government's priorities. Today swamp development in the country has a high priority. Rather than investing in costly inputs of fertilizer, high-yielding varieties, etc., the government should attempt to improve low-cost technology since ventures of this sort are already profitable, according to our estimates. This implies skipping established concepts like meticulous bush clearing, destumping, land leveling, etc. and compromising with what is realistic, given the labour and financial shortages. Gains would come from an increase in the area cultivated rather than from an increase in yields, the latter being badly offset by additional costs.

For example, transplanting of rice may be substituted by simple broadcasting of seed. The tedious work of destumping could be abandoned. The construction of internal bunds should be minimized but some cross-sectional bunds could be built to substitute for longitudinal drains.

As long as there is enough water for a wetland crop, the question of irrigation does not arise and should not become a part of swamp development work. Wherever a high technology has been used for swamp development in Sierra Leone, the schemes have failed from lack of maintenance, which is beyond the capacity of the swamp farmers. Development of different swamps becomes an issue within total watershed management and can only be dealt with by an established governmental body such as the Land and Water Development Division of the Ministry of Agriculture and Natural Resources of Sierra Leone. The steps needed include:

- A general inventory and classification of existing and potential swamp areas, suitable for development;
- Records of all swamps indicating location, utilization, and eventual stages of development;
- Research and demonstration in swamp development techniques and methods, primarily suitable for low-cost application;
- Encouragement of farmers to act in groups rather than preferential treatment for individual farmers and holdings;
- Organization of suitable farm-credit schemes, with long-term amortization either through commercial banks or special financing bodies;
- Long-term policymaking to ensure users' rights to a developed swamp and amortization of development costs by moderate levies (water cess) on developed lands (eventually a revolving fund); and
- An institutional framework that will ensure a unified approach to swamp development.

Without doubt, the swamplands of West Africa hold the greatest potential for an increase in rice production and are often the only land resource now available to be used on a sustained basis. Nevertheless, they cannot be developed without consideration of watershed management of the uplands.

DISCUSSION SUMMARY

In Bida Agricultural Development Project, do farmers receive any subsidy? Who is responsible for the maintenance of roads and other infrastructural facilities constructed by the project?

Each participating farmer receives NGN 20/season for weeding and field preparations. The project provides funds for construction of roads, which the state and local governments are to maintain and repair. However, maintenance depends upon the finances of the local governments.

What is the percentage of milling recovery of the rice varieties grown in the Bida area?

Most of the varieties planted in the area have a milling recovery rate between 60% and 70%.

What effort has been made to accelerate the spread of improved tools and implements to smallholders in Nigeria?

ADPs and national extension services are distributing and demonstrating tools with assistance from international organizations such as IITA (particularly for training of blacksmiths in fabrication of simple tools such as the rolling injection planter).

Given experiences gained in Nigeria and Sierra Leone, how effective are the ADPs in the long run?

Farmers and national programs must take advantage of the technical and financial support from ADPs to develop their own long-term, self-supported systems.

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